Dynamic Simulation of Shipboard Electric Power Systems

by
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Abstract

It is the aim of the proposed research to develop digital computer simulation models for a typical shipboard electric propulsion system, conduct dynamic analyses and determine viable control schemes for such a system. Electric propulsion for shipboard use is being considered as an attractive alternative to the geared diesel and gas turbine mechanical drives currently being used in most naval ships. Prior to building an electric propulsion drive system, the dynamic behavior must be understood and methods for controlling the system have to be determined.

A shipboard electrical system is small in size and has fewer components than a typical commercial power distribution system. A typical combatant ship may have three or four generators with a combined capacity of 80-100 megawatts. Most of this capacity is used by the propulsion motors, which for a two shaft ship will be rated in the range of 35-40 megawatts each. These loads, which are large with respect to the generating capacity, make the analysis of shipboard electrical systems more difficult than typical commercial power systems. Many of the simplifying assumptions used in the analysis of commercial power systems are not valid with shipboard systems. This complication requires a detailed model of the entire system including the relevant dynamics of each component.

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Title: Associate Professor of Electrical Engineering

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Chapter 1: Introduction

Electric drive systems have been used in naval ships for over 80 years. In the past, they have been characterized by higher initial cost, lower efficiency and greater space and weight requirements than mechanical drive systems. Their primary advantage over mechanical systems has been the high degree of control over the propeller and the degree of flexibility afforded to the naval architect in locating the propulsion equipment within the ship [1].

The advent of modern power electronics for implementing variable speed motor drives using synchronous or induction motors has made electric propulsion much more attractive. In recent years various types of electric drive propulsion systems have been proposed to reduce or alleviate some of the historical drawbacks of the electrical propulsion system, especially in the area of system efficiency.

The U.S. Navy has indicated its desire to develop and produce a modern electric propulsion system for its ships. However, the dynamic behavior of electrical networks required for such propulsion systems is not well understood. This research develops tools which can be used to investigate the dynamic behavior of typical electric drive systems under various operating conditions. It also attempts to determine a viable means for controlling such an electric drive system.

1.1 Shipboard Propulsion Systems

The current state of the art for naval surface ship propulsion systems consists of two diesel or gas turbine engines coupled to the propeller shaft through clutches and a mechanical transmission. This type of propulsion system allows the use of either one or both engines to drive the propeller. Above a certain ship speed, the ship's speed is controlled by varying the engine speed. When it is desired to move slower than the idle speed of the engine or to apply reverse power, the mechanical means provided to accomplish this comes in the form of a variable geometry propeller or a fluid coupling with reversing capability.

This configuration provides redundancy of main engines in case of battle damage and for conducting underway maintenance. It also allows for disconnecting both engines from one shaft, letting the shaft "trail," and driving the ship with its other shaft to improve fuel economy for certain ship speeds.

In mechanical systems of this type it is difficult to combine engines of different types on the same propeller shaft. They also do not allow for cross-connecting both propellers to one engine as is possible with older steam powered ships. Mechanical drives also require separate prime movers to generate electricity for ship's service loads. Another major disadvantage of mechanical propulsion systems is the necessity of providing mechanical alignment between the main engines and the propeller. This requires the engines to be located low in the ship. However, the light weight and large air intake and

exhaust requirements of modern gas turbine engines makes it highly desirable from an arrangement standpoint to locate them relatively high in the ship. This more efficient arrangement of engines is only possible with an electric drive ship.

Historically, there have been primarily two types of electric ship propulsion: ac synchronous and direct current. In standard practice, ac synchronous systems are essentially a synchronous generator or generators directly connected to a synchronous propulsion motor. The speed ratio between the generators and motor is a constant determined by the ratio of poles in the machines. In ac synchronous systems control of the ship's speed is accomplished by varying the speed of the generator prime mover. For reverse operation, the phase sequence to the motor is reversed. During maneuvering situations when synchronism cannot be maintained, the motor is operated as an induction motor. This results in a low power factor that reduces efficiency. Ac systems tend to be more reliable, efficient and lighter in weight than dc systems of the same power rating. They are also available in larger power ratings than dc systems [1].

Standard dc systems consist of multiple dc generators connected directly to dc motors. Commutation requirements limit both the system voltage and generator speed. Power handling equipment such as circuit breakers limit the current. These restrictions confine the power of dc systems to around 10,000 horsepower per shaft. This power level makes dc systems infeasible for most naval ship applications [1].

Despite their historical drawbacks, modern electric drives have numerous advantages over mechanical systems. Electric propulsion systems are able to be

cross-connected and power any one or both propellers from any prime mover. It is also possible to parallel diesel and gas turbine generators to drive the same shaft. Electric power cables are flexible and easily routed as compared to steel propulsion shafting, allowing the naval architect to place engines almost anywhere within the ship. The paralleling ability of electric propulsion systems allows the use of an odd number of engines, since the power of an engine may be split electrically between two propulsion shafts. As naval gas turbines only come in discrete sizes, this allows the generating capacity to be more closely matched to the load requirements. Propulsion derived ship's service electric power (PDSS) allows the elimination of separate prime movers for ship's service power generation. Electric propulsion systems provide more redundancy of key components for surviving battle damage and for maintenance. All of these features of electric propulsion systems make them very attractive at a time when fiscal constraints make cost and efficiency a prime consideration in warship design.

1.2 Analysis of Shipboard Electric Systems

Previous research into shipboard electric power systems, references [2],[3] and [4] has focused on developing algorithms for numerically solving the systems of equations which describe the shipboard electrical system and determining the stability of various components within the system. As of yet, there has been no research into the stability, performance and control of complete shipboard electric drive systems.

The analysis of shipboard electric distribution and propulsion systems is significantly different from commercial power systems analysis. The assumption of constant frequency is not valid for shipboard systems. During large transients the frequency will vary by a significant amount from its nominal value. Electrical, mechanical and control dynamics all exhibit similar time constants, therefore the technique of time scale separation will not work with shipboard systems. In a shipboard system, some of the loads are of a similar order of magnitude as the generators, thus the dynamics of that load must be considered. Additionally, the concepts of an "infinite bus" and a "slack bus" are not applicable to shipboard power systems. These difficulties require utilizing a dynamic model for each major component of the system. Each of these dynamic component models must be connected together in such a way as to properly simulate the electric power system.

The systems to be considered are quite simple from a power systems standpoint (i.e., one to three generators driving one or two motors either through frequency converters or directly). By using dynamic models of each component, accurate predictions of system performance can be obtained. However, the complexity of the overall system using full order component models does not lend itself to analytical solution. Therefore, digital computer simulations will be employed in the conduct of this research, and reduced order models will be used where appropriate.

The full order model of the power system constitutes a system of nonlinear differential equations which are subject to algebraic constraints. The algebraic constraints

arise as a result of Kirchoff's voltage and current laws. The differential equations come from the dynamic models of the various components. The resulting system of differential/algebraic equations (DAE's) poses a difficult numerical problem which many numerical simulation programs cannot handle. Various modeling techniques will be used in order to avoid the algebraic loops inherent in DAE systems.

1.3 Computer Simulation Tools

A survey was conducted of various software packages to determine their acceptability for conducting computer simulations of shipboard power systems. Some of the programs are:

<u>PSPICE</u>: Simulation Program with Integrated Circuit Emphasis (SPICE) is a program intended for circuit analysis [5]. PSPICE is a pc-based version of the original. This program is unacceptable for the proposed research because it cannot handle nonlinear implicit components.

<u>SIMULAB</u>: Simulab is a graphical interfaced general purpose program for simulating dynamic systems [6]. It can accept Matlab M-files or C-language coded components and can handle nonlinear implicit loops. Simulab contains several numerical integration algorithms, however it does not include a method for solving differential/algebraic equations. This algorithm could be hand coded into the program as a function if necessary.

<u>WAVESIM</u>: This program was developed specifically to simulate shipboard electric distribution systems [3]. The unique feature of this program is that it treats the state variables as continuous waveforms. However, the current implementation of WAVESIM depends on the software package MATLAB to perform its calculations, resulting in a very slowly running program. However, several of the component models are already in existence and have been thoroughly validated.

ACSL: Advanced Continuous Simulation Language, (ACSL) is a general purpose interactive simulation program which uses a language very similar to FORTRAN [7]. It has the ability to handle implicit nonlinear systems where it uses the Newton-Raphson method for solution of the algebraic constraint equations. However, it slows down appreciably when these systems are modeled.

After review of the capabilities and limitations of the above simulation programs, ACSL was selected as the tool to perform the required simulations as it appears to be best suited to handling the systems under consideration, and there are several component models already written and available for use.

1.4 Control of Shipboard Propulsion Systems

The control systems for current mechanical drive ships consist of a digitally implemented control algorithm which adjusts propeller pitch with constant propeller speed up to a certain speed. The propeller speed is then varied by adjusting fuel flow into the engines in an open loop fashion. The commanded speed is input with a single lever either from the ship's bridge (primary) or from the Engineering Central Control Station (CCS) (secondary). There is also an ability to control manually each prime mover's speed and propeller pitch separately from the engine room. This manual control is intended only for emergency operation.

Electric drive ships are more complicated than mechanical drive ships from a control standpoint. In addition to controlling the power output of the prime mover, there are several other system inputs which must be controlled. Specifically, the generator and

motor excitation, system frequency and the electronic motor drive must all be correctly controlled for the system to work properly.

Excitation of the generator will determine its power factor and maximum electrical power output. This must be matched (after losses) by the power input from the prime mover. These two variables determine the electrical power available to the system. However, motor excitation determines the maximum torque which can be produced by the motor. This requirement will vary depending on the speed and maneuvering requirements of the ship [8].

In past electric drive ships, the frequency of the propulsion bus was varied to change the ship's speed. In the modern systems which are proposed, the propulsion bus frequency will be held constant (probably at 60 Hz.), and the motor drive will convert this constant frequency power to whatever frequency is needed to drive the propulsion motor at the correct speed. This conversion is accomplished through the timing of the thyristers in an inverter circuit [9]. The advantage of this arrangement is that the fuel efficiency of the prime mover is improved by operating it at a constant speed. This type of design also allows the ship's service electrical load to be supplied off the propulsion bus which eliminates the need for separate generators.

For ease of operation and commonality with existing ships, it is desired to retain a "single-stick" control for electric drive ships. However, the additional inputs of the electric drive require a more sophisticated control system than is presently installed on mechanical drive ships. A closed loop system will be required to maintain the constant

propulsion bus frequency. Similarly, the motor drive electronics will need a closed loop controller.

1.5. Research Approach

This research studies the dynamic behavior of likely configurations of an integrated electric drive ship under both normal and abnormal operating conditions as well as fault conditions. Possible control schemes for these systems are also investigated for their suitability.

The ship which will be studied is the next generation amphibious ship, known as the LX. All major components of the propulsion electric bus will be modeled. These include the synchronous generators and their associated prime movers, propulsion motors, frequency converters and the propeller load on the motors. The propulsion derived ship's service load will be modeled as a single lumped parameter constant power load (see figure 1-1). This research is divided into four major tasks. These tasks are:

I. Identify system configurations to be studied.
II. Develop computer models for system components.
III. Integrate component models into system models.
IV. Conduct simulations and evaluate results.

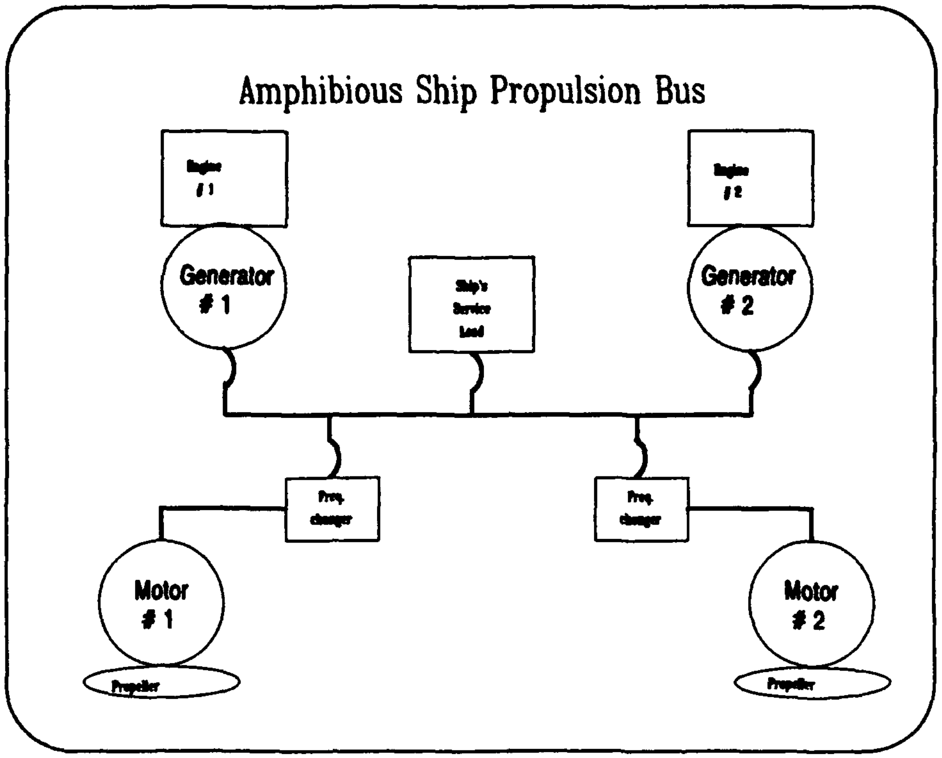

Amphibious Ship Propulsion Bus
Generator
1
Generator
2
Motor
1
Motor
2

Figure 1-1

Chapter 2: Component Models

In order to conduct simulations of an entire shipboard electrical system, it is necessary to derive models of the various components which make up the system. This chapter describes the various component models which make up the system under consideration. The ACSL code for the following models is located in Appendix A.

2.1 Synchronous Machine

The synchronous machine model used in this study is based on the derivation in [10]. This model assumes linear magnetics and sinusoidal winding distribution. There are three windings on the stator and three on the rotor. The stator windings are the three phase windings. The rotor windings are the field winding and the direct and quadrature axis damper windings, which are lumped-parameter representations for various distributed paths of current flow in the rotor. In order to generate a tractable model it is necessary to transform the stator variables into a reference frame which is rigidly attached to the rotor of the machine. The transformation which accomplishes this is the well known Park's transformation, which is given by:

$$T = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{2.1}$$

and the inverse transformation is:

$$T^{-1} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \tag{2.2}$$

$$\text{where,}\quad \underline{F}_{dq} = \begin{bmatrix} f_d \\ f_q \\ f_0 \end{bmatrix} = T \cdot \underline{F}_{abc}$$

$$\text{and,}\quad \underline{F}_{abc} = \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = T^{-1} \cdot \underline{F}_{dq}$$

Note that $\underline{F}$ is a vector place holder which represents voltage, current or any other quantity to be transformed. This version of the Park transformation will be used throughout this research.

The d and q subscripts correspond to the direct and quadrature axes, respectively. The direct axis is aligned with the field, and the quadrature axis leads the field by 90 degrees. The zero-sequence variables are not used unless unbalanced conditions are considered. Only balanced conditions will be considered in this research.

The synchronous machine model is given by the following set of equations from [10]:

$$\frac{d\psi_d}{dt} = -\frac{\psi_d}{T_{ad}} + \frac{e_q''}{T_{ad}} + \omega \cdot \psi_q + \omega_o \cdot v_d \tag{2.3}$$

$$\frac{d\psi_q}{dt} = -\omega \cdot \psi_d - \frac{\psi_q}{T_{aq}} - \frac{e_d''}{T_{aq}} + \omega_o \cdot v_q \tag{2.4}$$

$$\frac{de_q''}{dt} = -\frac{x_d'}{x_d''} \cdot \frac{e_q''}{T_{do}''} + \frac{e_q'}{T_{do}''} + \left(\frac{x_d' - x_d''}{x_d''}\right) \cdot \frac{\psi_d}{T_{do}''} \tag{2.5}$$

$$\frac{de_d''}{dt} = -\frac{x_q}{x_q''} \cdot \frac{e_d''}{T_{qo}''} - \left(\frac{x_q - x_q''}{x_q''}\right) \cdot \frac{\psi_q}{T_{qo}''} \tag{2.6}$$

$$\frac{de_q'}{dt} = -\alpha \cdot \frac{e_q'}{T_{do}'} + (\alpha - 1) \cdot \frac{e_q'}{T_{do}'} + \frac{e_{af}}{T_{do}'} \tag{2.7}$$

$$\frac{d\delta}{dt} = \omega - \omega_o \tag{2.8}$$

$$\frac{d\omega}{dt} = \frac{\omega_o}{2H}\left[T_m + \frac{\psi_d \cdot e_d''}{x_q''} + \frac{\psi_q \cdot e_q''}{x_d''} + \psi_d \cdot \psi_q \cdot \left(\frac{1}{x_q''} - \frac{1}{x_d''}\right)\right] \tag{2.9}$$

where the following definitions have been made:

$T_{ad} = \dfrac{x_d''}{\omega_o \cdot r_a}$ = Direct axis armature time constant

$T_{aq} = \dfrac{x_q''}{\omega_o \cdot r_a}$ = Quadrature axis armature time constant

$T_{do}'' = \dfrac{x_{kd}}{\alpha \cdot \omega_o \cdot r_{kd}}$ = D-axis open circuit sub-transient time constant

$T_{qo}'' = \dfrac{x_{kq}}{\omega_o \cdot r_{kq}}$ = Q-axis open circuit sub-transient time constant

$T_{do}' = \dfrac{x_f}{\omega_o \cdot r_f}$ = D-axis open circuit transient time constant

$$\alpha = \frac{x_d - x_d''}{x_d' - x_d''}$$

$e_q' = \dfrac{x_{ad}}{x_f} \cdot \psi_f$ = Voltage behind transient reactance

$e_q'' = \dfrac{x_{ad}}{x_{kd}} \cdot \psi_{kd}$ = Voltage behind sub-transient reactance

$e''_d = -\frac{x_{aq}}{x_{kq}} \cdot \psi_{kq}$ = Voltage behind sub-transient reactance

Stator currents in the following model are given in generator coordinates by:

$$\psi_d = e''_q - x''_d \cdot i_d, \text{ and } \psi_q = -e''_d - x''_q \cdot i_q \qquad (2.10)$$

The transients of interest are electromechanical ones with time constants in the range of 0.1 seconds to 10 seconds or longer. The stator equations (2.3) and (2.4), have eigenvalues on the order of 0.0026 seconds ($1/\omega_o$). Since integration routines used for computer simulation typically require time steps smaller than the smallest eigenvalue in the system, including the stator transients and resistance requires a high overhead in simulation time. Neglecting stator transients requires making the following assumptions: $\omega \gg \frac{d}{dt}, \frac{1}{T_{ad}}, \frac{1}{T_{aq}}$. These assumptions are valid under balanced conditions for all times and frequencies which will be studied herein. These simplifications are common practice when simulating electrical networks [11]. After making these approximations, equations (2.3) and (2.4) reduce to:

$$v_q = \frac{\omega}{\omega_o} \cdot \psi_d, \text{ and } v_d = -\frac{\omega}{\omega_o} \cdot \psi_q \qquad (2.11)$$

Substitution of (2.10) into (2.5), (2.7), (2.9) and (2.11) yields the following model:

$$v_d = \left(e''_d + x''_q \cdot i_q\right) \cdot \frac{\omega}{\omega_o} \qquad (2.12)$$

$$v_q = \left(e''_q - x''_d \cdot i_d\right) \cdot \frac{\omega}{\omega_o} \qquad (2.13)$$

$$\frac{de''_q}{dt} = -\frac{e''_q}{T''_{do}} + \frac{e'_q}{T''_{do}} - \frac{\left(x'_d - x''_d\right)}{T''_{do}} \cdot i_d \qquad (2.14)$$

$$\frac{de_d''}{dt} = -\frac{e_d''}{T_{qo}''} + \frac{\left(x_q - x_q''\right)}{T_{qo}''} \cdot i_q \tag{2.15}$$

$$\frac{de_q'}{dt} = -\alpha \cdot \frac{e_q'}{T_{do}'} + (\alpha - 1) \cdot \frac{e_q''}{T_{do}'} + \frac{e_{af}}{T_{do}'} \tag{2.16}$$

$$\frac{d\delta}{dt} = \omega - \omega_o \tag{2.17}$$

$$\frac{d\omega}{dt} = \frac{\omega_o}{2H}\left[T_m - e_d'' \cdot i_d - e_q'' \cdot i_q + i_d \cdot i_q \cdot \left(x_d'' - x_q''\right)\right] \tag{2.18}$$

For the generators which operate near rated frequency, the additional assumption of $\omega \approx \omega_o$ can be made. This modifies the above motor model by eliminating the factor of $\frac{\omega}{\omega o}$ from equations (2.12) and (2.13). By using the D and Q-axis currents as inputs, this form of the model is most useful for system studies.

2.2 Frequency Changer

A solid-state frequency changer is used to supply variable frequency AC power to the synchronous propulsion motor while the bus frequency is held constant. The particular frequency changer used in this study is a DC-link load commutated controlled rectifier-inverter. The derivation which follows is similar to those found in references [9] and [12]. Figure 2-1 shows the circuit configuration of this device. Notice that the converter is symmetric about the DC-link, thus only the inverter side need be analyzed. The equations of the rectifier are identical with appropriate substitution of variables. If the DC-side voltage and current are considered constant and instantaneous commutation is assumed, then the AC-side waveforms are as shown in figure 2-2. The two thirds cycle

pulse wave current waveform shown is somewhat idealized. The actual current wave pulses will exhibit a finite rise and decay time which is associated with the inductive elements in the AC side of the converter. This is known as commutation overlap. In the interest of creating a more tractable model for system studies, the commutation overlap effect will be neglected, which is consistent with other models for system level studies [12]. The currents can then be represented by their Fourier series:

$$i_a = \frac{2\sqrt{3}}{\pi} I_{dc} \cdot \left[\sin(\omega t - \beta_i) - \frac{1}{5}\sin 5(\omega t - \beta_i) - \frac{1}{7}\sin 7(\omega t - \beta_i) \cdots \right]$$

$$i_b = \frac{2\sqrt{3}}{\pi} I_{dc} \cdot \left[\sin\left(\omega t - \frac{2\pi}{3} - \beta_i\right) - \frac{1}{5}\sin 5\left(\omega t - \frac{2\pi}{3} - \beta_i\right) - \frac{1}{7}\sin 7\left(\omega t - \frac{2\pi}{3} - \beta_i\right) \cdots \right]$$

$$i_c = \frac{2\sqrt{3}}{\pi} I_{dc} \cdot \left[\sin\left(\omega t + \frac{2\pi}{3} - \beta_i\right) - \frac{1}{5}\sin 5\left(\omega t + \frac{2\pi}{3} - \beta_i\right) - \frac{1}{7}\sin 7\left(\omega t + \frac{2\pi}{3} - \beta_i\right) \cdots \right]$$

Transforming these currents into the rotating reference frame of the motor using eq. (2.1) gives:

$$i_d = -\frac{2\sqrt{3}}{\pi} I_{dc} \cdot \sin\beta_i \qquad (2.19)$$

$$i_q = -\frac{2\sqrt{3}}{\pi} I_{dc} \cdot \cos\beta_i \qquad (2.20)$$

with harmonic components neglected.

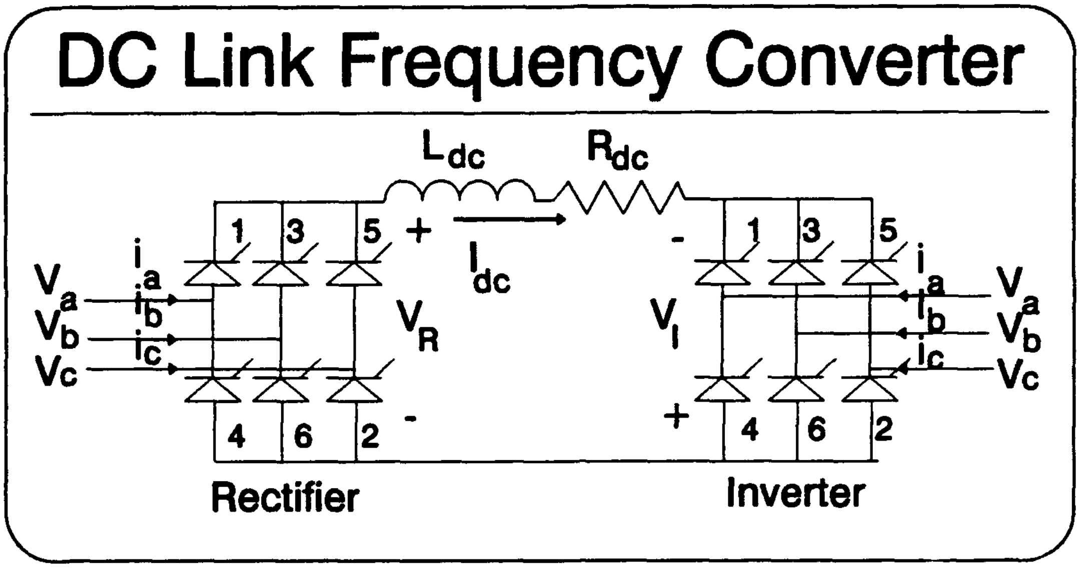


Figure 2-1

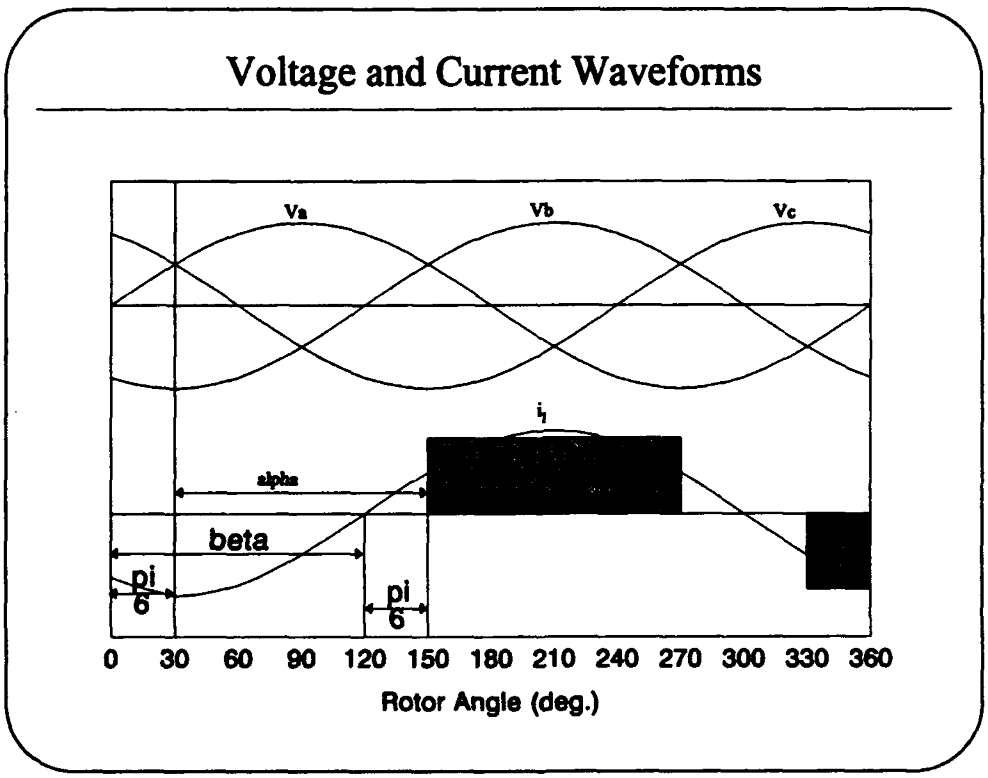


Figure 2-2

The voltages across the bridge may be related using the average value voltage equation [11]:

$$V_i = \frac{3\sqrt{3}}{\pi} E_{pi} \cdot \cos\alpha_i \tag{2.21}$$

$$\text{where: } E_{pi} = \sqrt{v_{di}^2 + v_{qi}^2} \tag{2.22}$$

$$\alpha_i = \beta_i \tag{2.23}$$

A similar analysis on the rectifier yields:

$$i_{dr} = -\frac{2\sqrt{3}}{\pi} I_{dc} \cdot \cos\beta_r \tag{2.24}$$

$$i_{qr} = -\frac{2\sqrt{3}}{\pi} I_{dc} \cdot \sin\beta_i \tag{2.25}$$

$$V_r = \frac{3\sqrt{3}}{\pi} E_{pr} \cdot \cos\alpha_r \tag{2.26}$$

$$E_{pr} = \sqrt{v_{dr}^2 + v_{qr}^2} \tag{2.27}$$

$$\alpha_r = \beta_r \tag{2.28}$$

Writing KVL around the DC link and solving for the time derivative results in the one state equation contained in the frequency changer model:

$$\frac{dI_{dc}}{dt} = \frac{1}{L_{dc}}[V_r + V_i - R_{dc} \cdot I_{dc}] \tag{2.29}$$

Equations (2.19) - (2.29) constitute the rotating reference frame model of the dc-link frequency changer used throughout this analysis. This model inputs ac side voltages and

outputs ac side currents. The rectifier and inverter firing angles, which control the converter are also inputs to this model.

2.3 Voltage Regulator

The voltage regulator model is a standard PI type controller which varies the field excitation of the generator in response to changes in terminal voltage. The terminal voltage is calculated from the d and q-axis voltages as:

$$V_T = \sqrt{V_d^2 + V_q^2}$$

The regulator dynamics are given by:

$$\frac{E_{af}}{V_{ref} - V_T} = \frac{K}{\tau s + 1} \qquad (2.30)$$

Where: V_{ref} = Reference terminal voltage
E_{af} = Generator field excitation
K = Voltage regulator gain
τ = Voltage regulator time constant

Satisfactory values of K and τ have been determined to be 100 and 0.1, respectively. This model also includes a limiting function on the value of E_{af}. The inputs to this model are the D-axis, Q-axis and reference terminal voltages. Its output is the field excitation.

2.4 Induction Motor

The vast majority of the ship's service electrical load on any ship consists of induction motors which power various pumps, fans and other equipment. In order to simulate the effect of a large transient in the ship's service load an induction motor model was developed from the derivation contained in [11]. The equations describing the induction motor in the synchronously rotating reference frame are given by:

$$\frac{d\psi_{ds}}{dt} = \omega_o \cdot (v_d - r_s \cdot i_{ds} + \psi_{qs}) \tag{2.31}$$

$$\frac{d\psi_{qs}}{dt} = \omega_o \cdot (v_q - r_s \cdot i_{qs} - \psi_{ds}) \tag{2.32}$$

$$\frac{d\psi_{dr}}{dt} = (\omega_o - \omega_m) \cdot \psi_{qr} + \frac{\omega_o \cdot r_r}{x_{lr}} \cdot (\psi_{md} - \psi_{dr}) \tag{2.33}$$

$$\frac{d\psi_{qr}}{dt} = -(\omega_o - \omega_m) \cdot \psi_{dr} + \frac{\omega_o \cdot r_r}{x_{lr}} \cdot (\psi_{mq} - \psi_{qr}) \tag{2.34}$$

$$\frac{d\omega_m}{dt} = \frac{\omega_o}{2H}(T_e + T_m) \tag{2.35}$$

$$\psi_{md} = x_{ad}\left(\frac{\psi_{ds}}{x_{ls}} + \frac{\psi_{dr}}{x_{lr}}\right) \tag{2.36}$$

$$\psi_{mq} = x_{aq}\left(\frac{\psi_{qs}}{x_{ls}} + \frac{\psi_{qr}}{x_{lr}}\right) \tag{2.37}$$

$$i_{ds} = \frac{1}{x_{ls}}(\psi_{ds} - \psi_{md}) \tag{2.38}$$

$$i_{qs} = \frac{1}{x_{ls}}(\psi_{qs} - \psi_{mq}) \tag{2.39}$$

$$T_e = (\psi_{ds} \cdot i_{qs} - \psi_{qs} \cdot i_{ds}) \tag{2.40}$$

where: ψ_{ds} = D-axis stator flux linkage
ψ_{qs} = Q-axis stator flux linkage
ψ_{dr} = D-axis rotor flux linkage

ψ_{qr} = Q-axis rotor flux linkage
ψ_{md} = D-axis mutual coupling flux linkage
ψ_{mq} = Q-axis mutual coupling flux linkage

The inputs to this model are the terminal voltages and mechanical torque, the outputs are the terminal currents and rotor speed. Stator transients are included in this model to eliminate algebraic loops. Primarily, the dynamics of interest are the rotor transients.

2.5 Ship's Service Load

Since one of the objectives of this research is to simulate an integrated electric drive ship, it was considered necessary to include the ship's service load. This was developed as a constant power load using the concept of complex power [12]. In complex form, the power in the rotating reference frame is given by:

$$P + jQ = \hat{V} \cdot \hat{I}^* = (v_d + jv_q) \cdot (i_d - ji_q) = (v_d i_d + v_q i_q) + j(v_q i_d - v_d i_q) \quad (2.41)$$

Solving for i_d and i_q yields:

$$i_d = \frac{v_d P + v_q Q}{v_d^2 + v_q^2} \qquad \text{and, } i_q = \frac{v_q P - v_d Q}{v_d^2 + v_q^2} \quad (2.42)$$

This results in a model with voltages as inputs and currents as outputs. P and Q are input parameters which are set to desired constants. For a more realistic loading which varies randomly about a mean, P and Q can be made random variables instead of constants.

2.6 Diesel Engine

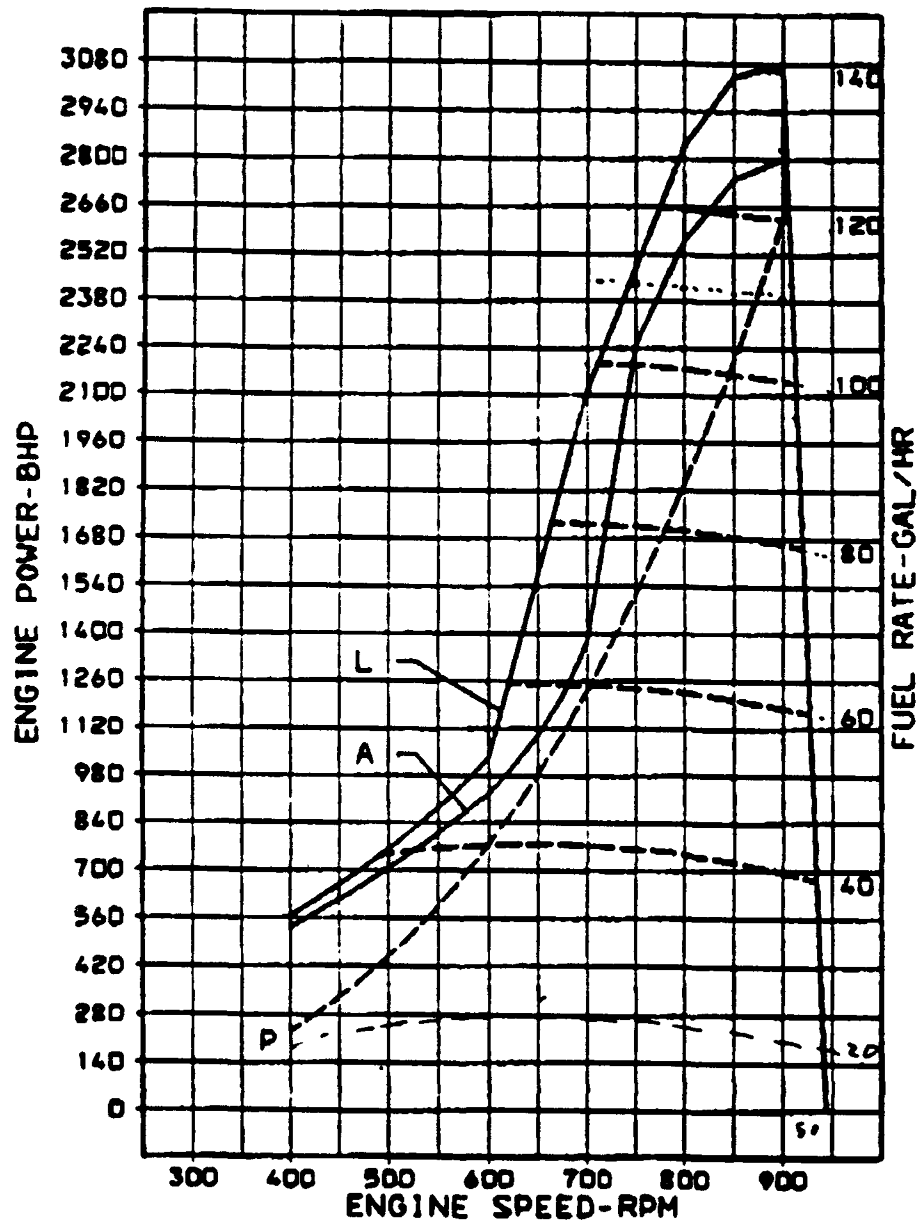
Typical models of diesel engines for engine analysis found in the literature include the dynamics of the combustion process, as well as the thermodynamic and heat transfer aspects to the engine. This type of model is much more complex than is necessary for the present purposes. Towards that end, an empirical model was developed which models the torque output of the engine as a function of the fuel rack position, engine speed and load.

The model which was developed is based on similar ones by Woodward [14], Hendrics [15] and Fowler [16]. It consists primarily of an engine map (fig. 2-3) which determines the relationship between speed, torque and fuel rack position and the appropriate time delays. The time delays considered in this model are the fuel injection delay and the turbocharger lag.

If the engine receives a step change in its fuel rack position, the fuel injection delay arises because the change in fuel entering the cylinders does not occur until two complete revolutions of the crankshaft (for a four stroke engine) have occurred. According to Woodward [14], if the speed is not varied over a wide range this delay may be approximated as:

$$\tau_f = \frac{30}{N} + \frac{120}{Q \cdot N}, \text{ seconds} \tag{2.43}$$

where, N = Engine speed (RPM)
Q = Number of cylinders



3080
2940
2800
2660
2520
2380
2240
2100
1960
1820
1680
1540
1400
1260
1120
980
840
700
560
420
280
140
0
ENGINE POWER-BHP
140
120
100
80
60
40
20
FUEL RATE-GAL/HR
L
A
P
300
400
500
600
700
800
900
ENGINE SPEED-RPM

Figure 2-3

Since this engine model is to be used as a generator set, it will not see a wide range of speed variation and this type of delay can be considered adequate.

It would be desirable to use a "compressor map" which represents the pressure ratio and efficiency of the turbocharger compressor as a function of mass flow rate and turbocharger speed for modeling the turbocharger dynamics. However, this information was not available from the manufacturer. Instead a first order lag time constant was developed which resulted in the proper time scale behavior of the engine. This is similar to that used by Fowler [16]. Taylor [17] indicates that the time lag of a turbocharger is inversely proportional to the power output of the engine. The turbocharger lag is given by:

$$\tau_T = \frac{K_T}{(T_m + 1)} \tag{2.44}$$

where, K_T = Empirical Constant
T_m = Engine output torque

These two time delays are then summed together to produce the total time lag in output torque exhibited by the engine. The resulting dynamics resemble a first order lag with a variable time constant. Unfortunately, dynamometer test data was not available for this particular engine, so a quantitative evaluation of the model was not made. However, the speed and torque response characteristics of this model compared favorably with those of [25] and [26] on a qualitative basis.

2.7 Diesel Engine Governor

In order to use the diesel engine as a generator prime mover, a speed regulating governor was developed. The diesel engine model described above uses the fuel rack setting as its control input. The governor which was developed is a PID type controller which acts on an error signal created by comparing the actual shaft speed with the desired speed of the engine. Its output is the fuel rack position. The governor can be represented as:

$$\frac{u}{e} = \frac{ks}{\tau s + 1} \qquad (2.45)$$

where: u = fuel rack position
e = speed error signal
k = controller gain
τ = controller time constant
s = Laplace operator

The PID controller was chosen over a PI controller due to the slow response of the diesel engine which can be attributable primarily to the turbocharger dynamics. When tuned to the particular engine being used, the gain and time constant values were determined to be 2 and 0.2 respectively. This model also includes a limiting function which only allows the fuel rack position to vary from zero to one as would be the case in a real engine.

2.8 Gas Turbine Engine

The gas turbine engine model that was used has been provided to the author by code 2753 of the Naval Surface Warfare Center (NSWC) detachment Annapolis, MD. It

is based on a detailed thermodynamic model of the General Electric LM-2500 marine engine which was developed using manufacturer's test bed data. This model consists of four parts:

1) The gas generator and power turbine module characterizes the two rotating shafts in the engine. When the compressor inlet temperature, pressure and fuel flow rate are input, this model calculates the torque and speed of both the free turbine which drives the compressor and the power turbine which drives the output shaft.

2) The main fuel control module simulates the dynamics of the fuel system on the engine. It calculates the fuel flow rate as a function of compressor inlet temperature, discharge pressure, speed and power level angle (PLA) actuator.

3) The free standing electronics enclosure (FSEE) module models the dynamics of the controller which is supplied as part of the engine installation. It determines the PLA as a function of throttle input command, power turbine shaft speed and inlet pressure and compressor inlet temperature and pressure.

4) For use as a generator, a limited PI type controller is used to maintain the power turbine shaft speed at a constant 3600 rpm.

With the exception of the speed controller, all of the modules use lookup tables to relate the input and output variables. The lookup tables are based on manufacturer's performance data from a real engine. Configuration and operational details of this engine can be found in reference [18]. Although this model is more detailed than actually

required for the control studies conducted herein, it is a proven accurate model of the most common gas turbine engine found in U.S. Navy ships. In order to eliminate duplication of effort, this model was used without changes.

2.9 Mechanical Load

A simple polynomial type mechanical load was used during the software testing phase to apply a load to the various prime movers and electric motors. This load is represented as:

$$T = a \cdot \omega^2 + b \cdot \omega + c \tag{2.46}$$

where: T = load torque
ω = per unit rotational speed
a = coefficient of speed squared term
b = coefficient of linear term
c = constant term

The coefficients are varied as necessary to exercise the model. This was written primarily as a convenience to allow running various loading conditions without recompiling the computer model being tested. The speed squared term allows the simulation of ship propulsion or fan loading on electric motors.

2.10 Ship Seaway dynamics

The ship seaway dynamics model was also provided to the author by code 2753 of NSWC Annapolis. This program models the propeller and hydrodynamic characteristics for a ship hull moving through the water in one degree of freedom. The hull resistance,

the propeller torque, and the propeller thrust characteristics have been per unitized. The characteristics, torque and thrust are represented as functions of per unit ship speed and per unit propeller shaft speed. The ship hull resistance function is characterized using a 10th order polynomial to fit the actual ship's data. This model also includes the friction torque function for the propeller shafts associated with the ship hull. The inputs are shaft speed in RPM on both shafts and the outputs are the shaft torque values. This model also allows the inclusion of a seaway loading on the propeller. This is a very important feature since the time varying torque on the propulsion motors significantly complicates the control problem. This will be discussed more thoroughly later. This model has also been validated so it is used without change.

Chapter 3: Interconnections

To simulate a complete electric propulsion system, it is necessary to connect the various component models together so that the simulation model resembles the actual system. Assembly of the computer model requires adherence to both the physical laws which describe the system as well as constraints imposed by the numerical implementation of the models on the computer. Since the physical system's electrical components are interconnected by transmission lines and switchboards, it is first necessary to develop a model for the transmission line. Switchboards are treated in the simulations as lossless switches and any losses that may be associated with the switchboards are lumped into the transmission line models.

3.1 Transmission Line Model

The transmission line model used in all analyses is simply a balanced three phase series R-L element as shown in figure 3-1. The voltage drop across the transmission line is:

$$\underline{V}_1 - \underline{V}_2 = L \cdot \frac{d\underline{I}}{dt} + R \cdot \underline{I} \qquad (3.1)$$

Where:

$$\underline{V_1} = \begin{bmatrix} v_{a1} \\ v_{b1} \\ v_{c1} \end{bmatrix}, \quad \underline{V_2} = \begin{bmatrix} v_{a2} \\ v_{b2} \\ v_{c2} \end{bmatrix}, \quad \underline{I} = \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

and, $$L = \begin{bmatrix} l & m & m \\ m & l & m \\ m & m & l \end{bmatrix}, R = \begin{bmatrix} r & 0 & 0 \\ 0 & r & 0 \\ 0 & 0 & r \end{bmatrix}.$$

The off-diagonal terms in the inductance matrix represent the mutual coupling between the phases. Transforming this into the rotating reference frame using equation (2.1) yields:

$$V_{1d} - V_{2d} = \frac{x}{\omega_o} \cdot \frac{di_d}{dt} - \frac{\omega}{\omega_o} \cdot x \cdot i_q + r \cdot i_d \tag{3.2}$$

$$V_{1q} - V_{2q} = \frac{x}{\omega_o} \cdot \frac{di_q}{dt} + \frac{\omega}{\omega_o} \cdot x \cdot i_d + r \cdot i_q \tag{3.3}$$

Where: $x = \omega_o \cdot (l - m)$

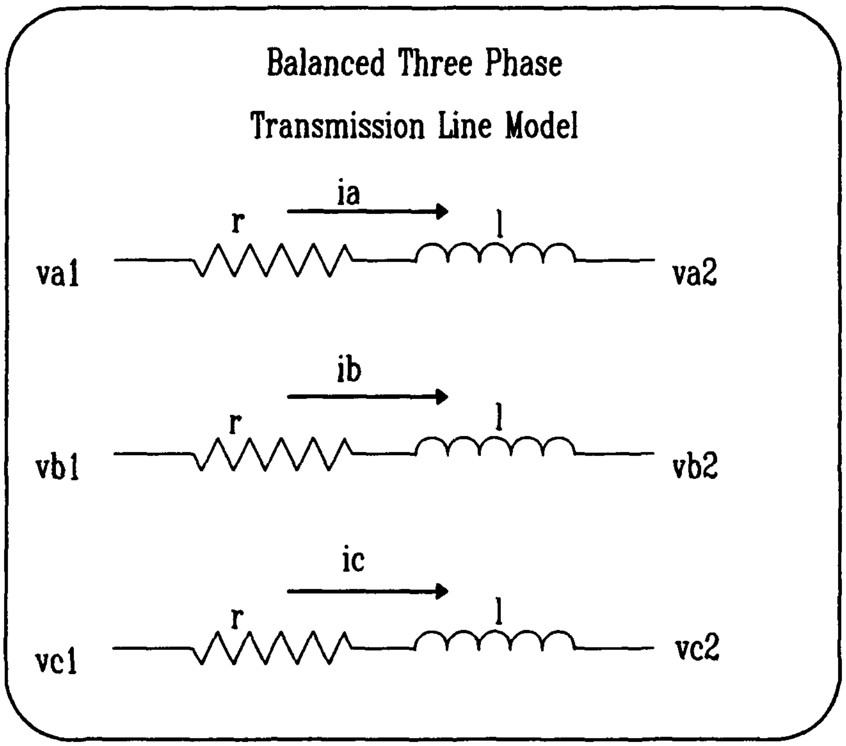


Figure 3-1

Shipboard transmission lines tend to have very small resistance values in comparison to commercial distribution systems, primarily due to their shorter length. For this reason the resistance terms in equations (3.2) and (3.3) can be neglected without loss

of accuracy. Similarly, since x is small and $\frac{d}{dt} \ll \omega, \omega_o$ for the time scale of interest, the transformer voltage terms may also be ignored leaving only the speed voltage terms. For the transmission lines that operate at bus frequency, we can further assume that $\omega \approx \omega_o$, which is the approach taken in [12]. The reduced order transmission line model then becomes:

$$V_{1d} - V_{2d} = -x \cdot i_q \tag{3.4}$$

$$V_{1q} - V_{2q} = \quad x \cdot i_d \tag{3.5}$$

This model is used to interconnect generators and loads via the main propulsion bus.

3.2 Physical and Numerical Considerations

The electrical component models must be interconnected such that Kirchoff's voltage and current laws (KCL and KVL) are obeyed. As mentioned previously, this leads to algebraic constraint equations in addition to the state equations contained in the various component models.

Besides these physical constraints, when modeling the system on the computer all variables must be explicitly calculated as a function of other variables somewhere within the simulation. Put more simply, every variable must appear on the left hand side of the equals sign exactly once in the simulation. As a result of this constraint, each component model has certain inputs and outputs. When connecting two models together, this input/output relationship must be taken into account, in addition to satisfying KCL and KVL.

In the case of two components connected electrically, it is very straightforward to satisfy the numerical and physical constraints simultaneously. If one component uses voltage as its input and calculates its required current from that voltage, and the other component uses current as its input and calculates a terminal voltage from its terminal current; then by setting the terminal currents and voltages of the two components equal to each other all constraints are satisfied. This assumes that the terminal variables of at least one of the components are related through one or more state variables. This is the case when the frequency changer model is connected to the synchronous motor model. The motor inputs currents and outputs voltages, whereas the frequency changer inputs voltages and outputs currents. Furthermore, the frequency changer's AC side current output is a function of the DC-link current (a state variable) and the thyrister firing angle. The problem becomes more difficult when three or more components are to be interconnected.

With multiple components connected to the same bus, the difficulty of the problem depends on what the input and output variables of each component are. In general, for a bus KCL can be written as: (d-axis, q-axis is similar)

$$i_{dg1} + i_{dg2} + \cdots + i_{dgn} = i_{dl1} + i_{dl2} + \cdots i_{dlm} \tag{3.6}$$

where there are n generators and m loads attached to the bus. This can be solved for any one of the currents if all the other currents are known (i.e., outputs of their respective component models). Equations (3.4) and (3.5) can be used to relate the terminal voltage of each component to the bus voltage. This represents a set of 2*(n+m+1) equations with

2*(n+m+1) unknowns. The easy solution to this problem is when there is exactly one component attached to the bus which inputs current and outputs voltage. In this case equation (3.6) can be solved for that component's currents, and its corresponding transmission line voltage equations can be solved for the bus voltages. Once the bus voltage is known, the terminal voltages of all other components can be calculated directly. This is exactly the case that occurs in the systems simulated with one generator operating.

In the case of multiple generator operations, the bus configuration has numerous components (the generators) which require currents as inputs. All load models have been configured with voltages as inputs. Equation (3.6) can no longer be explicitly solved since it has several unknown quantities, so another method for determining the bus voltage and generator currents must be found.

One approach is to modify the transmission line equations for all generators except one. This is accomplished by solving equations (3.2) and (3.3) for the time derivatives, making the currents state variables. Although this method can be made to work, it introduces a set of very fast eigenvalues that control the time step size of the simulation. It also is very sensitive to the transmission line impedance value and tends to introduce numerical instabilities into the system. Because of these difficulties, this method was not chosen to conduct two generator simulations.

Another approach is to use equations (2.12)--(2.18) with currents as inputs for one of the generators, and equations (2.3)--(2.10) with voltages as inputs for the other generators. This reintroduces the stator transients into the system for all the generators

except one, and is similar to the above method. While the stator transients are fast eigenvalues, they are not nearly as fast as those introduced by the transformer voltages in the transmission line. However, this method also seems to suffer from numerical stability problems of unknown origin. This method was not used for conducting two generator simulations.

A third approach is simply to solve the set of transmission line and stator voltage equations implicitly along with the current equations. ACSL has a built-in function to solve this type of implicit loop based on the Newton-Raphson method for solving simultaneous equations. Although the Newton-Raphson method in general is not always convergent [19], in this case the set of equations which must be solved is linear and no convergence problems were encountered. This method of solving the algebraic loop is preferred, and was used for all two generator simulations.

Since the system of equations is linear, it would also be possible to explicitly solve the system by collecting the equations together into a single vector equation and inverting the coefficient matrix. Although the matrix inversion would probably be faster than the implicit solution, ACSL doesn't handle matrix operations very eloquently. The result of this approach is that the object oriented structure of the simulation models would be compromised.

A fourth method for breaking the algebraic loop is simply to leave the loop in the simulation. This allows the computer to calculate the variables algebraically in the sequence in which they occur in the simulation. For example, given:

$v_{g1} = f(i_{g1})$ and $i_{g1} = f(v_{g1})$,

the simulation calculates these variables at each time step as:

$$v_{gl}^{n+1} = f\left(i_{gl}^{n}\right) \text{ and } i_{gl}^{n+1} = f\left(v_{gl}^{n+1}\right).$$

This is effectively a first order Euler integration of v and i. According to Crandall [20], the error of this method is on the order of *h* (the step size), which is kept below .01 seconds in the simulations. If the variables v and i are on the order of one, then this method is considered accurate enough for the purpose at hand. The ship's service load model described in chapter 2 uses this method to calculate its required current from its terminal voltage. The ship dynamics model also uses this method for calculating ship speed when a seaway is invoked.

3.3 Per-unitization

All the electrical models described in chapter 2 have been per-unitized. The choice of base values for per-unitization is arbitrary, but is usually selected to be the rated voltage and power when working with a single component. When several components of different ratings are connected in a system, one common base must be used throughout the system. For this research, this common base was chosen to be the rated values for the propulsion motor.

In the actual system, the voltage must be the same throughout or transformers must be supplied to connect components which operate at different voltages. If the base voltages are chosen in the same ratio as the transformer turns ratio for two components connected through a transformer, then the ideal transformer can be eliminated from the per

unit model of the system [21]. However, since the currents are related across a transformer by the inverse of the turns ratio, the currents in the per unit system must be converted from one base to another. The per unit base conversions are given by:

$$VA_{pu,2} = VA_{pu,1} \cdot \frac{VA_{base,1}}{VA_{base,2}} \tag{3.7}$$

$$V_{pu,2} = V_{pu,1} \cdot \frac{V_{base,1}}{V_{base,2}} \tag{3.8}$$

$$I_{pu,2} = I_{pu,1} \cdot \frac{V_{base,2}}{V_{base,1}} \cdot \frac{VA_{base,1}}{VA_{base,2}} \tag{3.9}$$

$$Z_{pu,2} = Z_{pu,1} \cdot \left(\frac{V_{base,1}}{V_{base,2}}\right)^2 \cdot \frac{VA_{base,2}}{VA_{base,1}} \tag{3.10}$$

Equation (3.9) is used to convert the terminal currents of the generators to the propulsion motor base in all simulations.

3.4 System Configurations

There are two configurations which have been considered during this research. They are both based on the system outlined in figure 1-1. The first system, known as "system 1" uses only one generator to provide electrical power. It is represented schematically in figure 3-2. The interconnection equations for this system are:

$$i_{dg1} = \frac{2 \cdot i_{dr1} + i_{dl2}}{ki_{g1m1}} \tag{3.11}$$

$$i_{qg1} = \frac{2 \cdot i_{qr1} + i_{ql2}}{ki_{g1m1}} \tag{3.12}$$

$$v_{dbus} = v_{dg1} + i_{qr1} \cdot x_{g1} \tag{3.13}$$

$$v_{qbus} = v_{qg1} - i_{dr1} \cdot x_{g1} \tag{3.14}$$

$$v_{dr1} = v_{dbus} + i_{qr1} \cdot x_{r1} \tag{3.15}$$

$$v_{qr1} = v_{qbus} - i_{dr1} \cdot x_{r1} \tag{3.16}$$

Where: ki_{g1m1} = per unit base conversion factor for generator #1.

Note that the value of x_{l2} has been taken as zero since the reactance of this transmission line can be accounted for in the power factor of the ship's service load.

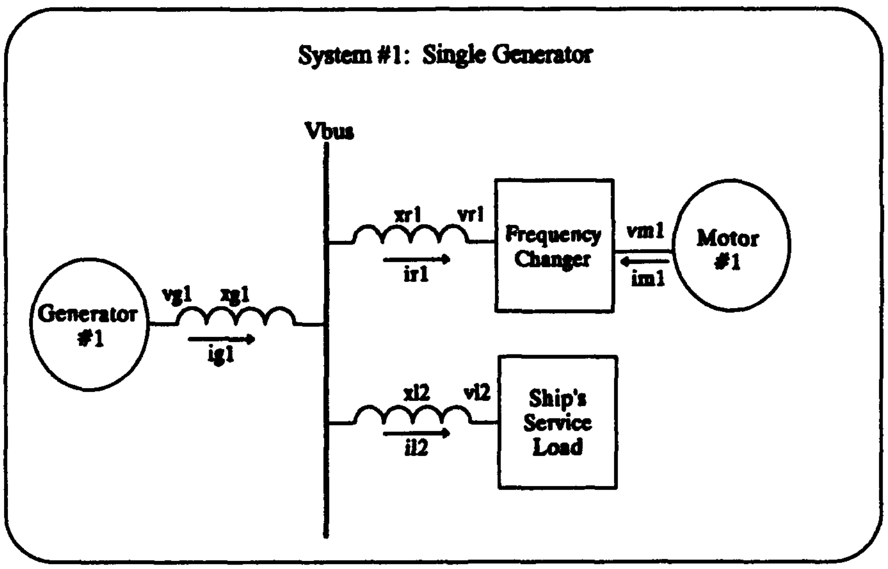


Figure 3-2

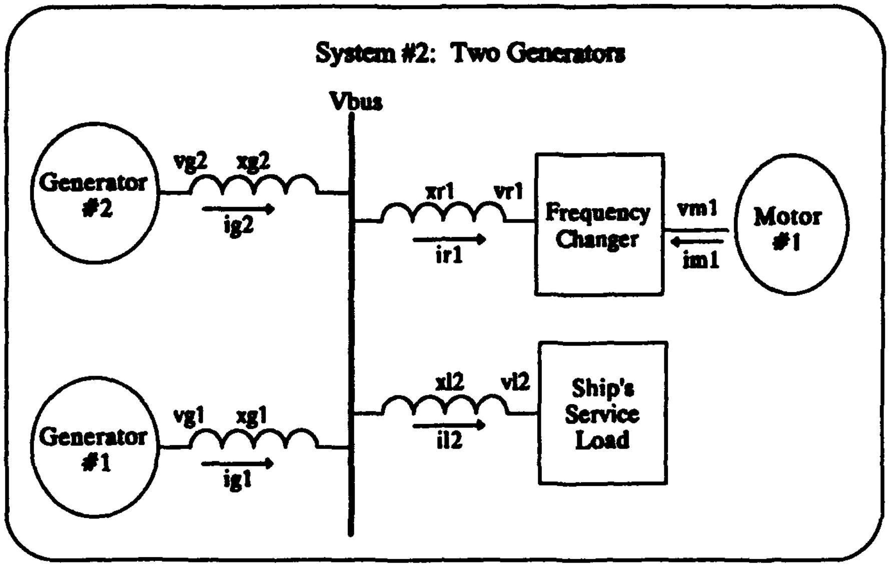


Figure 3-3

The second system, or "system 2" uses two generators and is pictured in figure 3-3. One of the generators is driven by a gas turbine and the other is driven by a diesel engine. The interconnection equations of this system are given by:

$$v_{dbus} = v_{dg1} + i_{qg1} \cdot x_{g1} \tag{3.17}$$

$$v_{qbus} = v_{qg1} - i_{dg1} \cdot x_{g1} \tag{3.18}$$

$$i_{qg1} = -\frac{(v_{dg2} - v_{dbus})}{x_{g2} \cdot ki_{g1m1}} \tag{3.19}$$

$$i_{dg1} = -\frac{(v_{qg2} - v_{qbus})}{x_{g2} \cdot ki_{g1m1}} \tag{3.20}$$

$$v_{dr1} = v_{dbus1} + i_{qr1} \cdot x_{r1} \tag{3.21}$$

$$v_{qr1} = v_{qbus} - i_{dr1} \cdot x_{r1} \tag{3.22}$$

$$i_{dg1} = \frac{(2 \cdot i_{dr1} + i_{dl2} - i_{dg2} \cdot ki_{g2m1})}{ki_{g1m1}} \tag{3.23}$$

$$i_{qg1} = \frac{(2 \cdot i_{qr1} + i_{qt2} - i_{qg2} \cdot ki_{g2m1})}{ki_{g1m1}} \tag{3.24}$$

Where: ki_{g2m1} = per unit base conversion factor for generator #2.

Both of the systems simulated for control studies use only one propulsion motor / frequency converter combination. This simplification was made to reduce computing time as all simulations were carried out on a personal computer. To properly simulate the load on the generators, the rectifier currents have been multiplied by a factor of two in equations (3.11), (3.12), (3.24) and (3.25) above. The only constraint placed on the system by this simplification is that maneuvering situations where each shaft is turning at different speeds (or directions) cannot be simulated. It is not necessary to simulate such situations for the present studies, however it is a simple programming change to add the second propulsion motor if such studies are undertaken at a later date. To verify this capability, some simulations were run with two propulsion motors attached to the bus with no problems encountered. The results of these simulations are presented in appendix C.

Chapter 4: Control Studies

With system modeling completed , it becomes possible to study the dynamic behavior of an integrated shipboard electrical drive and power distribution system. The aim of conducting control studies is to determine in general what type of controls are necessary to stabilize the system and provide adequate performance from an operational standpoint.

4.1 Inputs and Outputs

As mentioned in the introduction, there are several control inputs to the system. The primary controls are:

- Generator prime mover fuel rate.
- Generator field excitation.
- Motor field excitation.
- Rectifier and Inverter thyrister firing angles.

In addition to these controls there are other inputs which affect the system such as sensor noise and plant disturbances. The most significant form of plant disturbance is sea state induced variation in ship speed. This is the only disturbance which will be treated in this preliminary study. Sensor noise will not be addressed herein.

Additionally, there are several observable outputs of the system. The outputs which we are interested in controlling are:

- Bus voltage.
- Bus frequency.
- Motor torque.
- Motor speed.
- Ship Speed.

4.2 Voltage and Frequency Control

The prime mover fuel rate is used to control system frequency. This is accomplished by the speed governor. The voltage regulator uses the generator field excitation to control the bus voltage. Both of these variables are controlled in closed-loop fashion by the simple P-I type controllers described in chapter 2. The objective for controlling bus frequency and voltage is to maintain both at their constant set point values. For U.S. Navy ships, the requirements for electric power generation are found in MIL-STD-1399. Table 4-1 summarizes the voltage and frequency requirements contained therein.

	Frequency	Voltage
Nominal	60 Hz	440/115 Volts
Steady StateTolerance	$\pm$ 3%	$\pm$ 5%
Transient Tolerance	$\pm$ 4%	$\pm$ 16%
Worst Case Excursion	$\pm$ 5.5%	$\pm$ 20%

Table 4-1

4.3 Control of Inverter fed Motor

The propulsion motor speed and torque, and consequently the ship's speed are controlled by the rectifier and inverter firing angles and the motor field excitation. The following sections describe various schemes for controlling the propulsion motor / frequency changer combination.

4.3.1 Open Loop Volts/Hertz Control

This method of control is the one method true synchronous operation with an inverter-fed synchronous motor. In this method of control, the inverter frequency is a control input which uniquely determines the machine speed. As the load torque changes, the electromagnetic torque is developed by changes in the load angle δ. This is analogous to the operation of a synchronous motor attached to a conventional constant frequency supply. This type of control is used in voltage-fed inverters where the terminal voltage of the motor can be controlled in proportion to the supply frequency. By maintaining a constant volts/hertz ratio at the motor terminals, the airgap flux of the machine remains constant and maximum torque is developed at all speeds.

The main advantage of this method is that accurate control of machine speed can be achieved at all speeds. This control method is commonly used with permanent magnet and variable reluctance machines. Open loop control is not suitable for applications with high dynamic performance requirements, and consequently is not considered for ship propulsion applications [9].

4.3.2 Self-Controlled Synchronous Motors

This type of motor is also known as an electronically commutated motor (ECM), or a brushless dc motor because the torque-speed characteristics of the motor are similar to that of a mechanically commutated dc motor. The inverter bridge replaces the mechanical commutator, making the terminal characteristics at the dc side of the inverter identical to that of a mechanically commutated motor.

The self control method is a closed-loop scheme where the inverter frequency is slaved to the rotational speed of the motor. This is accomplished by the use of a position sensor on the motor to generate the inverter firing pulses. Some systems have replaced the position sensor with algorithms which determine the rotor position from the terminal voltages of the motor [22]. By using the rotor position to trigger the inverter firing, the motor can't fall out of step with the supply. This type of control is applicable to voltage or current-fed inverters as well as cycloconverters. Permanent magnet, variable reluctance or conventional wound rotor synchronous motors may be controlled in this manner.

In high power applications such as ship propulsion, this method is most commonly used with the LCI-fed synchronous motor. The electromagnetic torque of the motor is directly proportional to the dc-link current in this configuration. The motor speed is determined by the balance between the electromechanical and load torques. Consequently, the control system usually consists of a two-loop arrangement with the inner torque control loop controlling the dc-link current and the outer loop controlling the speed of the motor.

The rectifier firing angle is the control variable which is used to control the dc-link current. The field excitation of the motor is controlled to maintain a constant airgap flux, providing constant torque output for a given current level. This arrangement is pictured schematically in figure 4-1.

The load commutated inverter is most commonly found on high power applications since it is simpler in construction and exhibits lower power losses than forced commutated inverters [23]. It is limited by the fact that it requires the motor to operate at

a leading power factor to ensure thyrister commutation. Additionally, at low speeds (below about 10% of rated) the back EMF generated by the motor is insufficient to ensure thyrister commutation and some method of forced commutation must be employed. The simplest method of accomplishing this without introducing additional circuit elements is to pulse the dc-link current on and off. This does produce large pulsating torques, but in ship propulsion applications, that is not considered to be a serious drawback.

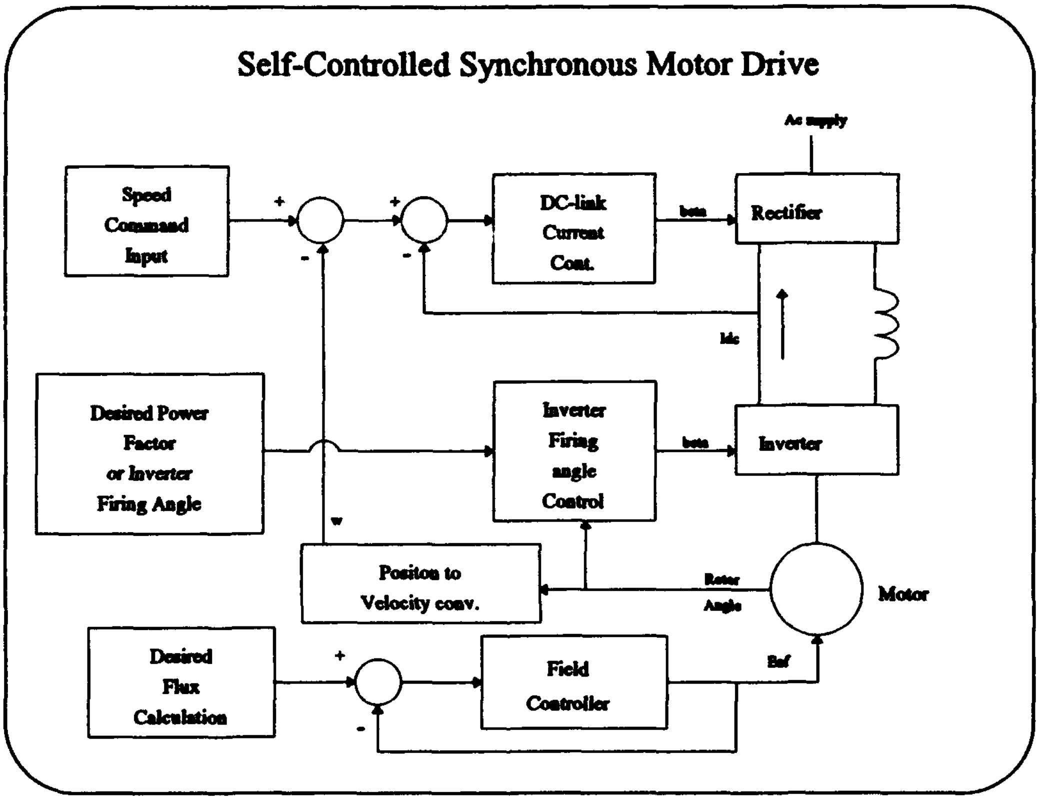


Figure 4-1

While the rectifier firing angle is used to control the motor torque, the inverter firing angle can be used to control the position of the stator current waveform relative to the stator voltage, thus controlling the power factor. This is known as constant margin

angle control and is one of two control schemes used in the simulations for control of the inverter firing angle. The other is simply to keep the inverter firing angle constant.

Obviously, the constant firing angle control is easier to realize, however the constant margin angle control offers several advantages. With constant margin angle control, the inverter firing angle and field excitation are controlled in unison to maintain the stator flux at a constant value as shown in figure 4-2. By maintaining the flux relationship shown in this phasor diagram, the leading power factor required for load commutation is ensured under all load conditions. This is not the case with constant firing angle control. Also, with constant firing angle control the power factor angle becomes quite large in the lightly loaded condition. This causes excessive VAR loading on the inverter [9].

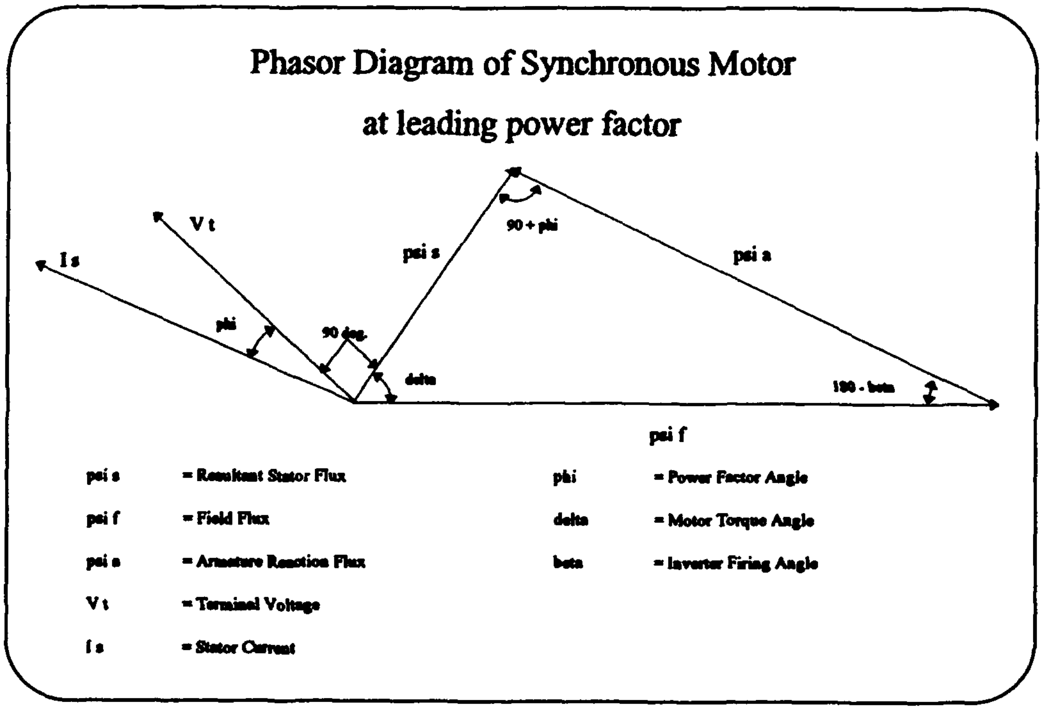


Figure 4-2

4.3.3 Vector Controlled Synchronous Motors

This type of control is also known as field oriented control. Vector control de-couples the field current from the torque component of stator current as is the case in mechanically commutated dc machines. This can be accomplished on an electronically commutated machine by operating at unity power factor. Since the LCI drive requires a leading power factor to ensure thyrister commutation, vector control is not possible with the LCI drive [23].

The primary purpose of using vector control over a self-controlled machine is to provide faster time response. For ship propulsion applications, the improved response is not needed because the ship dynamics are slower than the electrical dynamics and are the controlling factor in determining the motor's speed response. For these reasons, this type of control was not considered for use in the present simulations.

4.3.4 Motor Control for Ship Propulsion

All of the control schemes outlined above have been developed for applications where precise speed control of the motor is required. Precise speed control of the propulsion motor is not required or even desired in shipboard applications. This is due to the nature of the loading on the motor. The motor sees a load torque which is a quadratic function of speed in the steady state, but varies about its mean value as the ship encounters waves. This variation in loading is caused by the ship motions in the seaway and can become very significant in heavy sea states.

One approximation for this loading is used in the ship dynamics model described in chapter 2. This approximation assumes a single frequency sea induced sinusoidal variation

of the ship's speed. While this is a crude approximation at best, it does manage simulate the major influence the seaway has on the propulsion system, that of the time varying nature of the ship's speed as it traverses over large ground swells. This approximation does not account for any propeller racing which sometimes occurs as a result of the ship's pitching and rolling in a heavy sea state. It also does not account for the random nature and many frequencies of waves which make up a seaway.

Figure 4-3 shows a simulation run with a standard self-controlled synchronous motor drive system. The outer speed control loop uses a P-I type controller to maintain the motor speed. Note that the sinusoidal variation in ship speed shows up in the trace of motor torque. This variation propagates back through the electrical system causing a similar variation in the generator loading. Another simulation run with a different wave frequency was able to excite one of the natural modes of the gas turbine engine and cause a frequency oscillation as well. With this type of loading on the propulsion motor, it would be difficult if not impossible to maintain the power requirements in table 4-1 even in the steady state.

One solution to this problem would be to adjust the gain and time constant on the speed controller so that the sea induced load variation is faster than the response of the controller and would be attenuated as noise. The problem with this approach is that this requires a time constant on the order of 30+ seconds which would result in a very sluggish response to changes in the commanded speed input from the ship's bridge. On supertankers or Navy re-supply ships this type of response may be tolerated, however it is expected that combatant ships be able to stop and change speeds quickly.

To solve this problem of conflicting requirements, a two mode controller was developed which has a sluggish low gain band in the vicinity of zero speed error and a fast high gain response outside of this band. The low gain region allows the motor speed to vary in response to the sea induced loading variations while minimizing its effect on the main electrical bus and generators. The high gain region ensures a quick response to operator input. Figure 4-4 shows a block diagram representation of the two mode motor control used in the simulations. Figure 4-5 shows the response of the two mode controller to the same loading condition as that of figure 4-3. The two mode controller was used for all subsequent simulations.

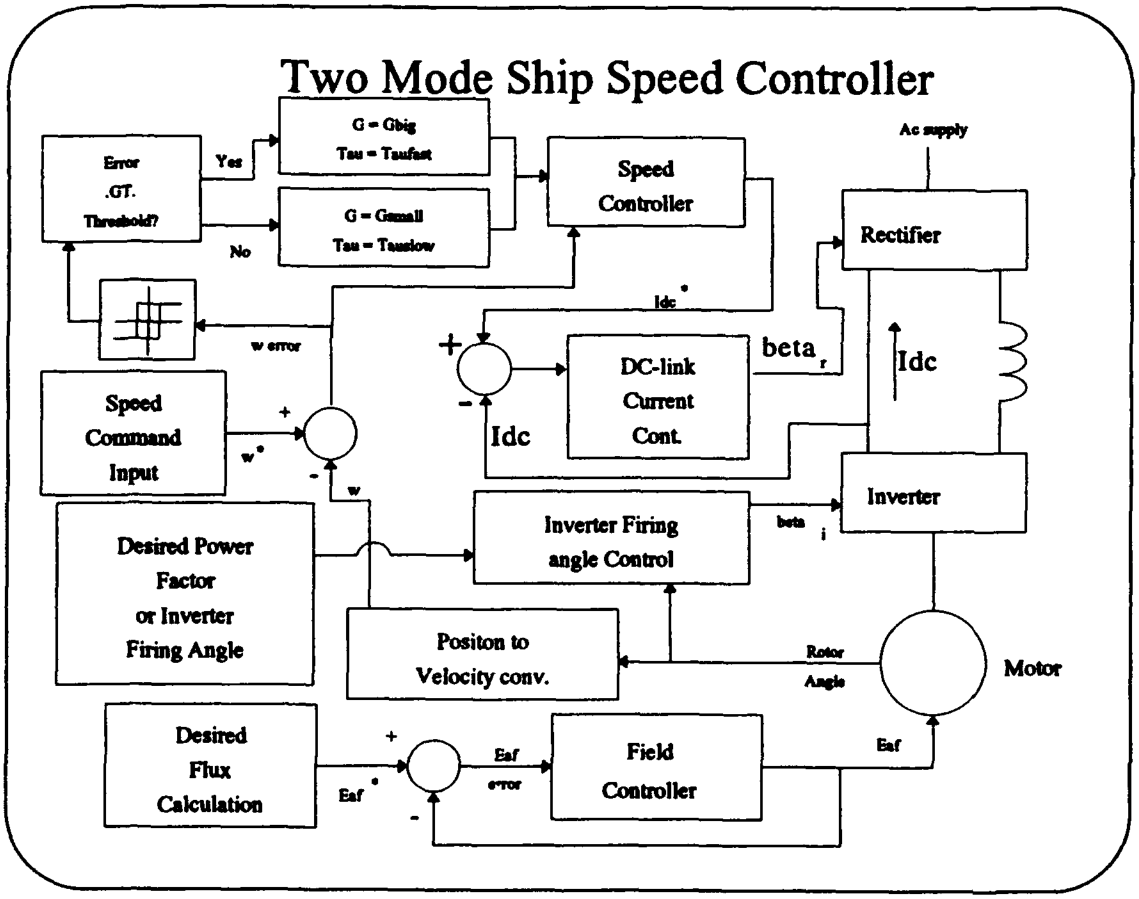


Figure 4-4

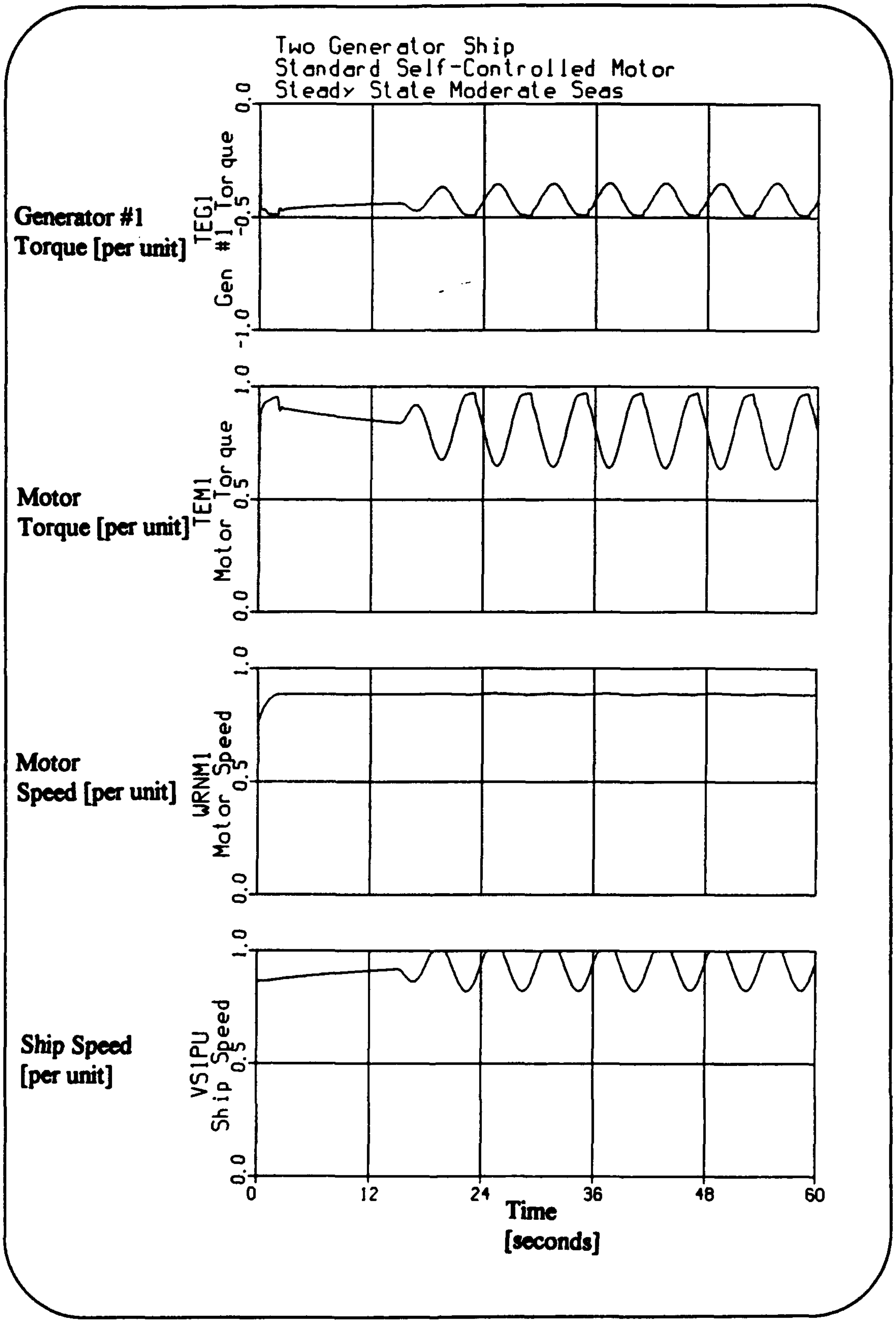

Two Generator Ship
Standard Self-Controlled Motor
Steady State Moderate Seas
Generator #1 Torque [per unit]
TEG1
Gen #1 Torque
Motor Torque [per unit]
TEM1
Motor Torque
Motor Speed [per unit]
WRNM1
Motor Speed
Ship Speed [per unit]
VS1PU
Ship Speed
Time [seconds]

Figure 4-3

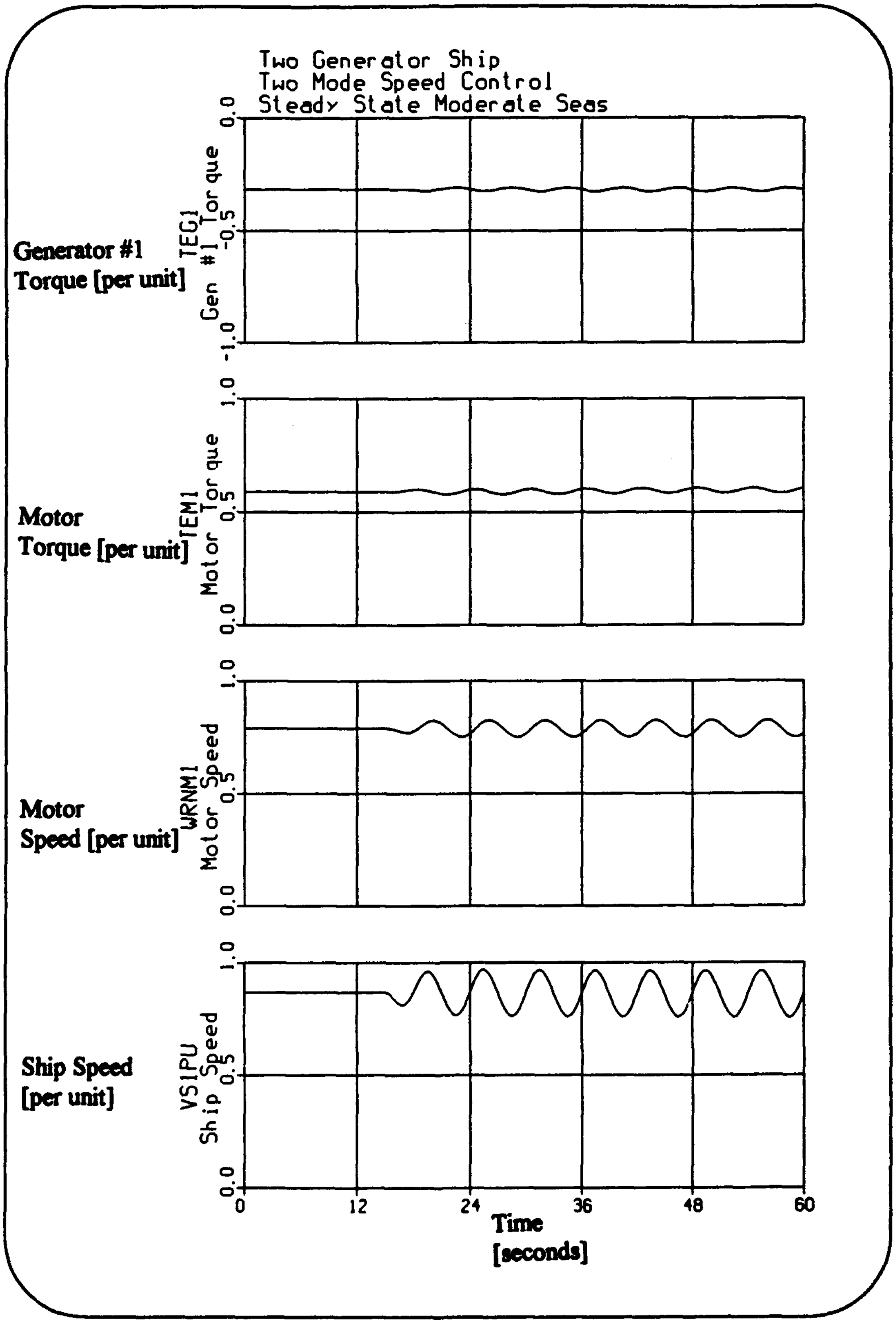

Two Generator Ship
Two Mode Speed Control
Steady State Moderate Seas
Generator #1 Torque [per unit]
TEG1
Gen #1 Torque
0.0
-0.5
-1.0
Motor Torque [per unit]
TEM1
Motor Torque
1.0
0.5
0.0
Motor Speed [per unit]
WRNM1
Motor Speed
1.0
0.5
0.0
Ship Speed [per unit]
VS1PU
Ship Speed
1.0
0.5
0.0
0
12
24
36
48
60
Time [seconds]

Figure 4-5

Chapter 5: Results and Conclusions

5.1 Simulation Results

Numerous simulations were conducted to verify the operation of the computer models and to evaluate the proposed control schemes. Both of the two systems outlined in chapter 3 were evaluated with similar results. The following sections describe some of the specific simulation runs. Complete graphical results are located in appendix D.

5.1.1 Two Generator Ship: Acceleration From Rest

In this run, the ship is simply accelerated from rest to a speed of 0.9 per unit. After running the simulation for 15 seconds to settle out the gas turbine speed, the shaft speed input setting is changed from 0.05 per unit to 0.9 per unit. This change in desired speed setting causes the dc-link current to increase to its maximum value, followed by the motor terminal currents. The motor speed rises to about 0.5 per unit in 4-5 seconds, then it accelerates at the same rate as the ship speed increases as shown in figure 5-1. Similarly, the motor terminal voltage builds up with the motor speed. This is what would be expected given the form of the motor and ship dynamics models. The two mode control switches into the "fast mode" when the input command is given. It switches back to the slow mode when the motor speed error is reduced to the threshold value of 0.1 per unit. There is no seaway invoked for this simulation.

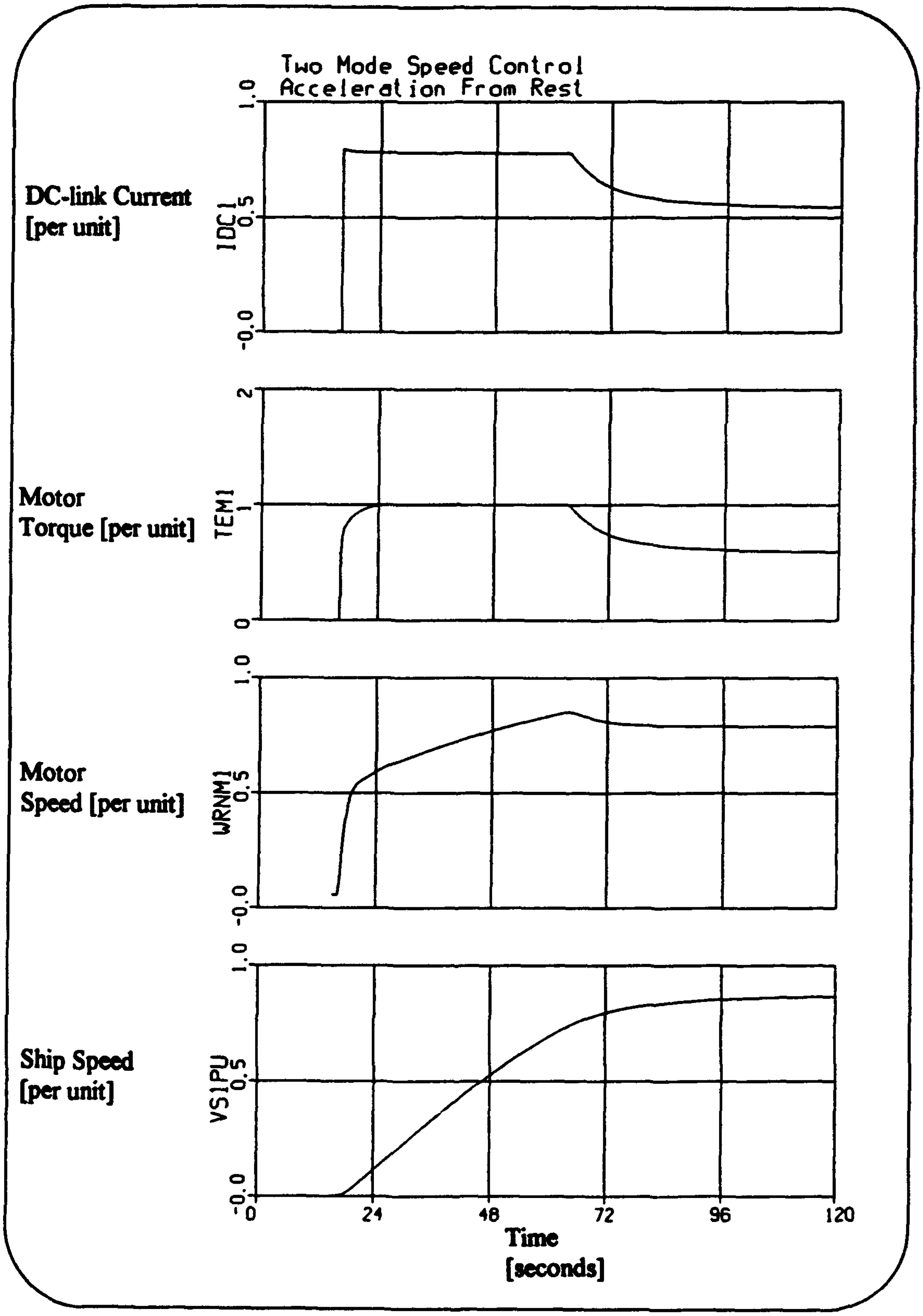

Two Mode Speed Control
Acceleration From Rest
DC-link Current
[per unit]
IDC1
1.0
0.5
-0.0
Motor
Torque [per unit]
TEM1
2
1
0
Motor
Speed [per unit]
WRNM1
1.0
0.5
-0.0
Ship Speed
[per unit]
VS1PU
1.0
0.5
-0.0
0
24
48
72
96
120
Time
[seconds]

Figure 5-1

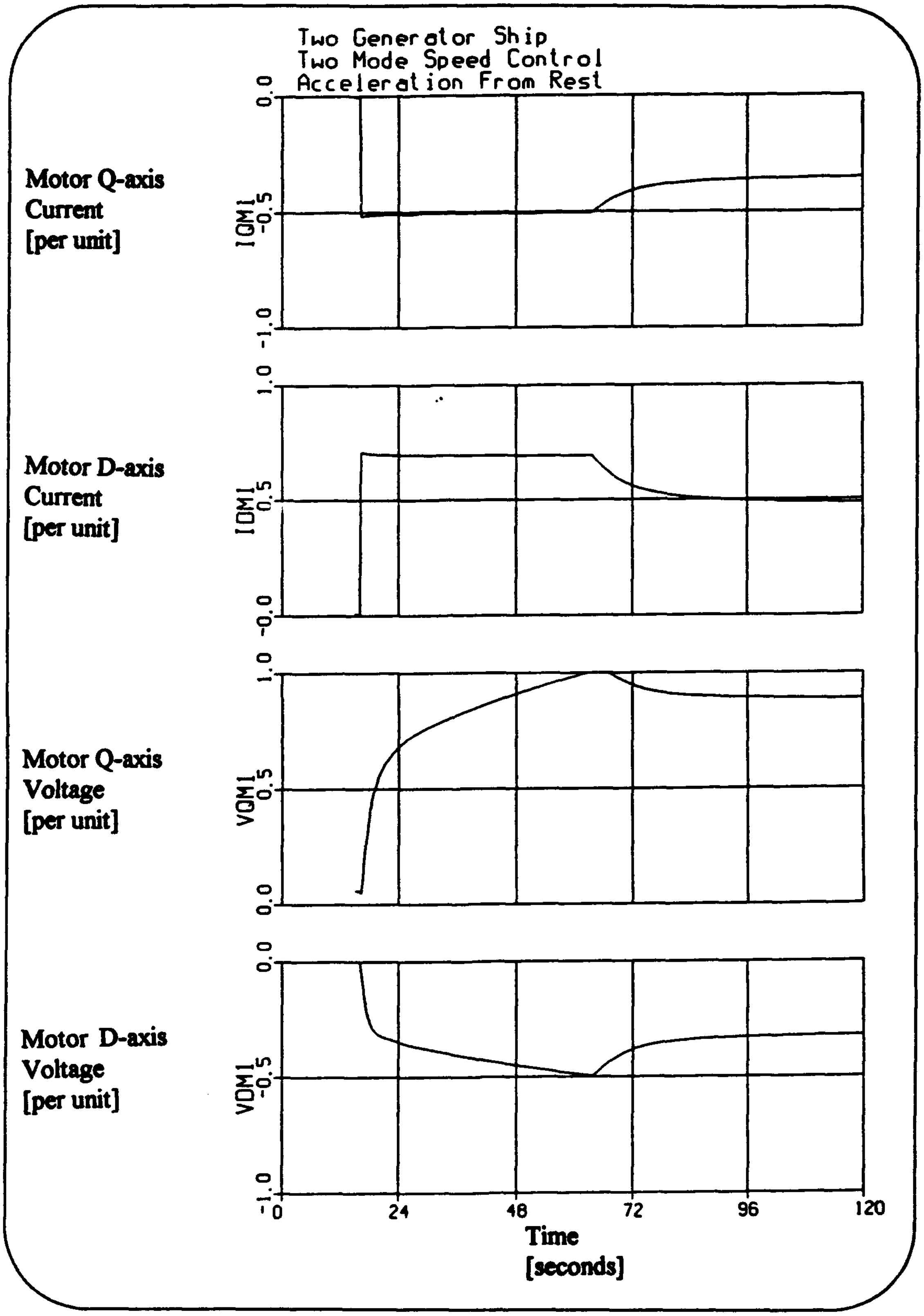


Figure 5-1 (continued)

5.1.2 Two Generator Ship: Moderate Sea State

This simulation was described in chapter 4. Currently, the threshold value for the switch from "fast mode" to "slow mode" has been optimized for the moderate sea state conditions in the ship dynamics model. In actuality, this threshold would be made somewhat larger to allow the ship to operate at steady state in any sea without the control system switching into the "fast mode".

The threshold value is now simply a constant value of speed error. Because of the low gain in the "slow mode", the system has a large steady state error which at lower speed settings becomes quite significant. A different technique would be to make the threshold value a constant fraction of the current desired speed setting. The above simulation was repeated after making this modification. The results at low speed settings showed improved steady state error, however at higher speed settings the system would switch back and forth between the fast and slow modes. With a little fine tuning of the constants, it is believed that this technique would work quite well.

5.1.3 Two Generator Ship: Crashback

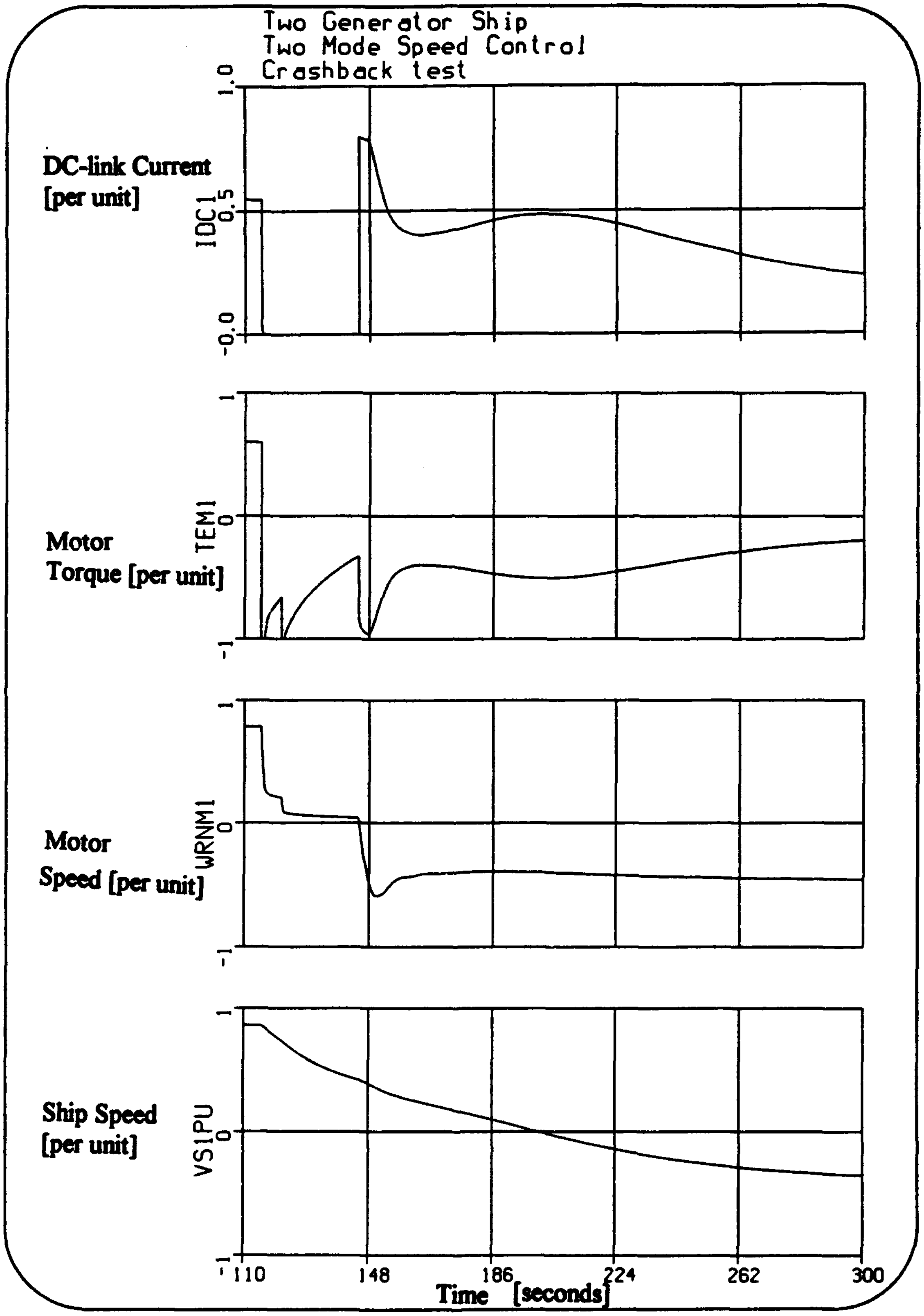
"Crashback" is the name given to the event that occurs when the ship is traveling ahead at a high rate of speed and reverse speed is ordered. This is the equivalent of slamming on the brakes in an automobile, and is an important measure of the maneuvering performance of the ship. It is also the harshest transient on any drive system, mechanical or electric. This was the most difficult simulation to run since it involved making a sequence of events occur in logical steps with the only input being the change of the speed input command.

This simulation begins with the ship operating at a steady speed of 0.9 per unit. At T=115 seconds, the speed setting is changed from 0.9 to -0.5 per unit. First, the rectifier firing angle is set to 90 degrees which causes the dc-link current to decay rapidly to zero. When it reaches zero, the inverter firing angle is also set to 90 degrees. This is done to keep the terminal voltage of the motor from reversing the dc-link current. These actions effectively isolate the motor from the propulsion bus.

Next, a braking resistor is applied across the terminals of the propulsion motor. This is initially set to a conductance value of 1.5 per unit. In figure 5-2 this can be identified by the first peak in motor torque and current. The motor rapidly slows to about 0.2 per unit speed, then decays slowly. When the terminal voltage decays to 0.3 per unit, the conductance is changed to 5.0 per unit causing the second torque peak and speed drop. This configuration is held until the motor speed drops to 0.04 per unit.

At this time the phase sequence of the inverter is reversed and the rectifier and inverter firing angles are returned to their normal controlled values. This action causes the third torque spike which stops the motor and causes it to reverse directions. As the motor continues rotating in reverse, the ship eventually stops and reverses direction also. This is also evidenced in figure 5-2.

This simulation run illustrates very well the difficult requirement of controlling this type of system such that the operator only has to give a single input to achieve the desired result. The controls demonstrated here are still quite rudimentary, however. The torque trace in figure 5-2 shows that the motor is over-torqued when the braking resistor is engaged and when its value is changed. A better method would be to use several steps of



Two Generator Ship
Two Mode Speed Control
Crashback test
DC-link Current
[per unit]
IDC1
1.0
0.5
-0.0
Motor
Torque [per unit]
TEM1
1
0
-1
Motor
Speed [per unit]
WRNM1
1
0
-1
Ship Speed
[per unit]
VS1PU
1
0
-1
110
148
186
224
262
300
Time [seconds]

Figure 5-2

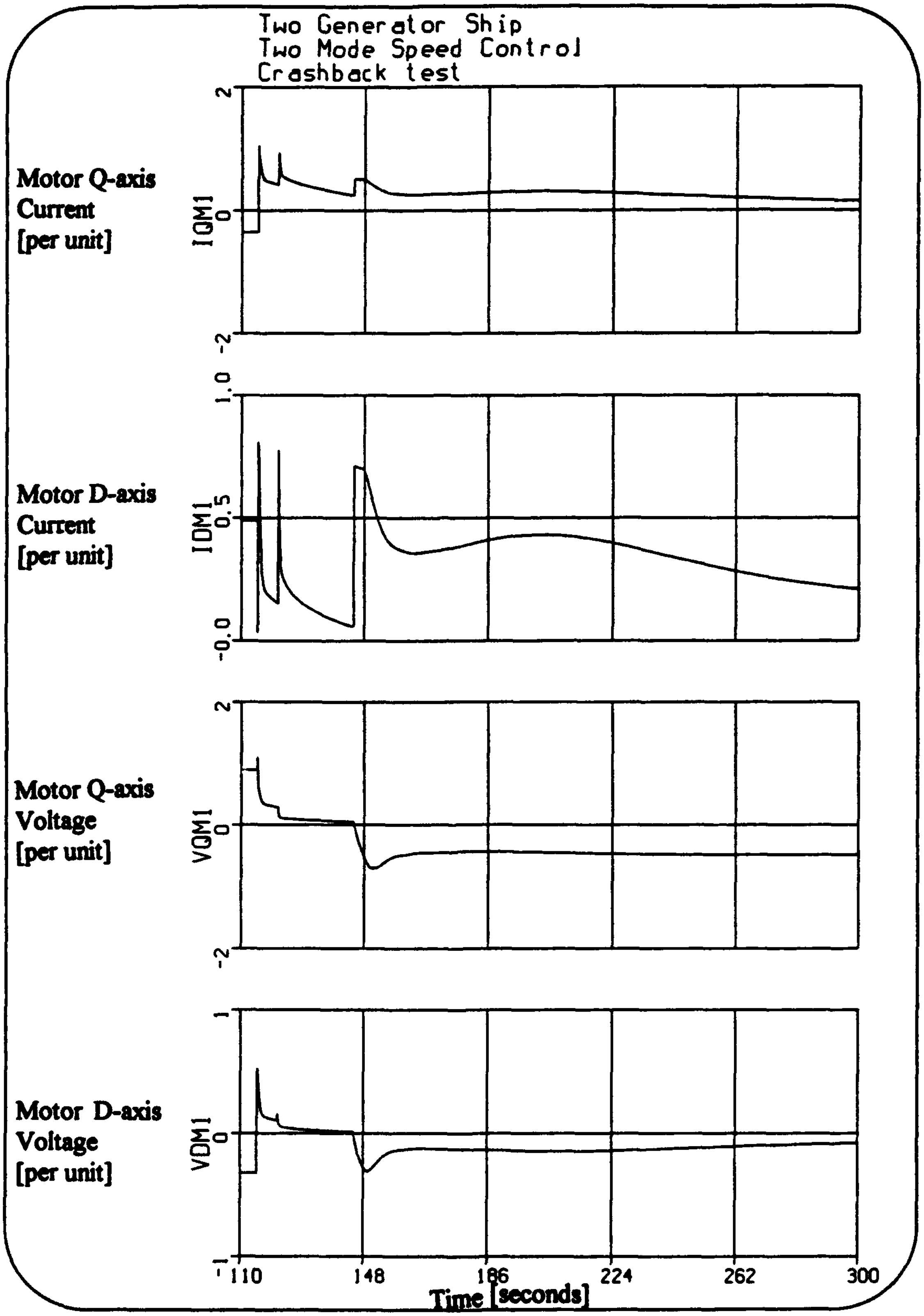


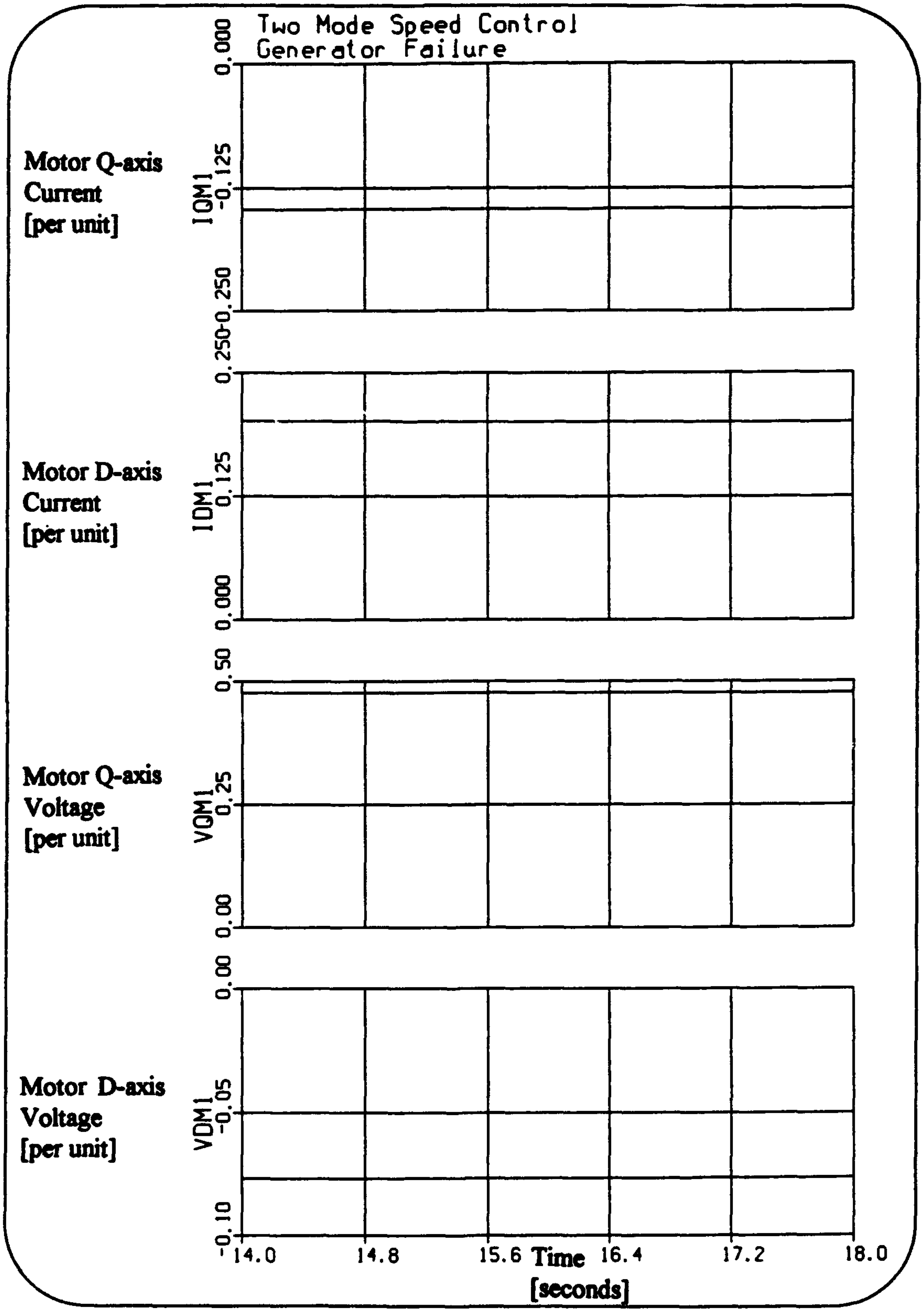
Figure 5-2 (continued)

resistor values to prevent this over-torque problem. A more sophisticated system would use the power generated in slowing the propulsion motor to supply the ship's service load by feeding it back to the bus through the frequency changer. This has been discussed at the concept level in conjunction with pulsed power weapons. The current simulation models are capable of simulating this mode of operation given the proper control system. Another feature which has not been looked into is limiting the rate at which the motor load is removed from the bus. Currently it is removed instantaneously which can cause a generator over-speed shutdown if the generator is highly loaded [24].

5.1.4 Two Generator Ship: Generator Failure

As the name implies this run simulates the results when one of the two generators is tripped off-line. Actually, this consists of two different runs. The reason for this is that the results are quite different for the two situations. In both cases generator #2 is disconnected from the bus, causing generator #1 (the gas turbine generator) to pick up the entire propulsion and ship service load.

In the first run, the speed input is set to 0.5 per unit. At T=15 seconds the generator #2 breaker is tripped, causing generator #1 to take the entire load. In this case, the combined propulsion and ship's service load is less than the capacity of generator #1, which successfully picks up the entire load as generator #2 shuts down. Notice in figure 5-3 that the motor variables are effectively constant during the entire period of transition from two to one generator.



Two Mode Speed Control
Generator Failure
Motor Q-axis
Current
[per unit]
IQM1
0.000
-0.125
-0.250
Motor D-axis
Current
[per unit]
IDM1
0.250
0.125
0.000
Motor Q-axis
Voltage
[per unit]
VQM1
0.50
0.25
0.00
Motor D-axis
Voltage
[per unit]
VDM1
0.00
-0.05
-0.10
14.0
14.8
15.6
16.4
17.2
18.0
Time
[seconds]

Figure 5-3

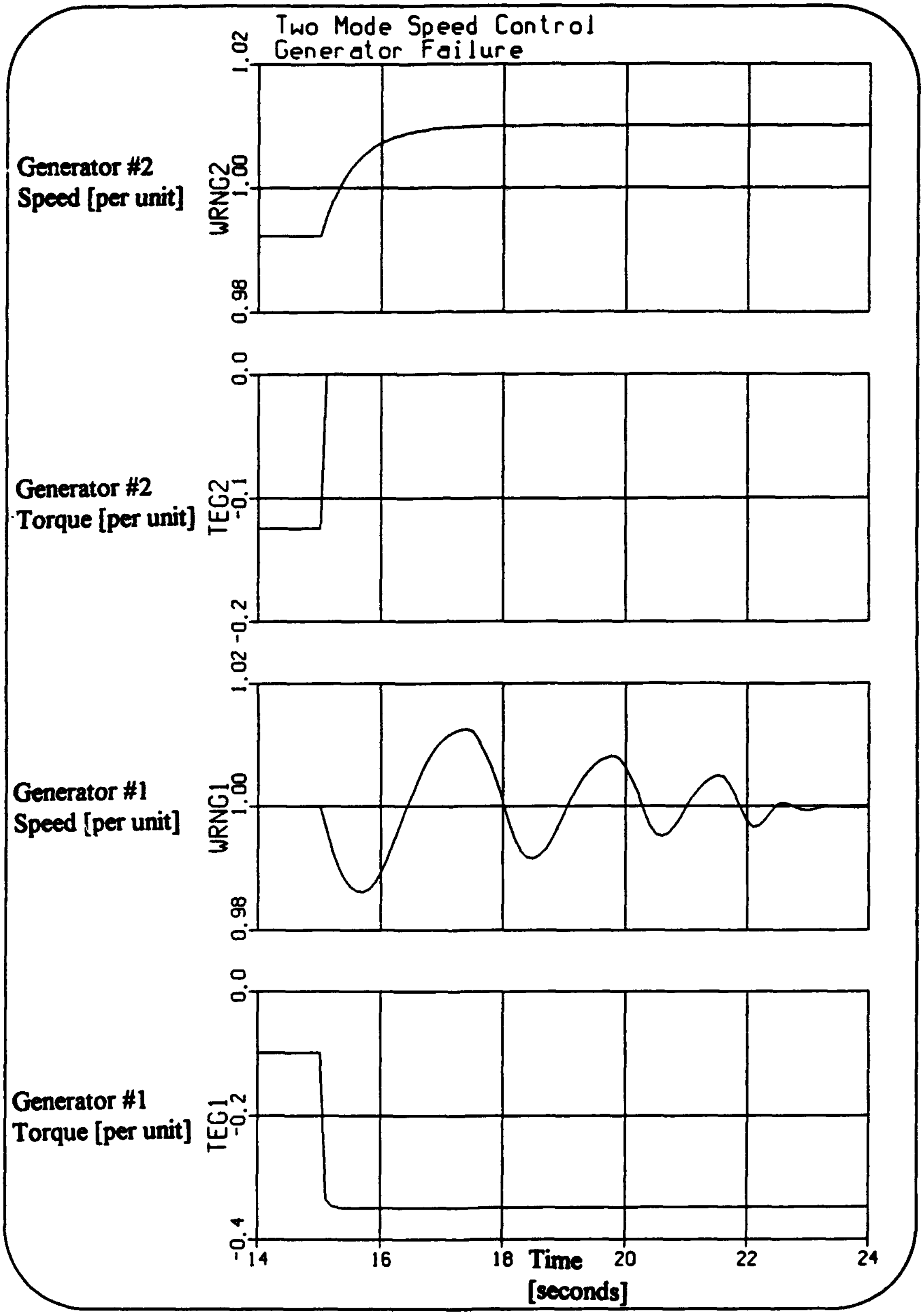
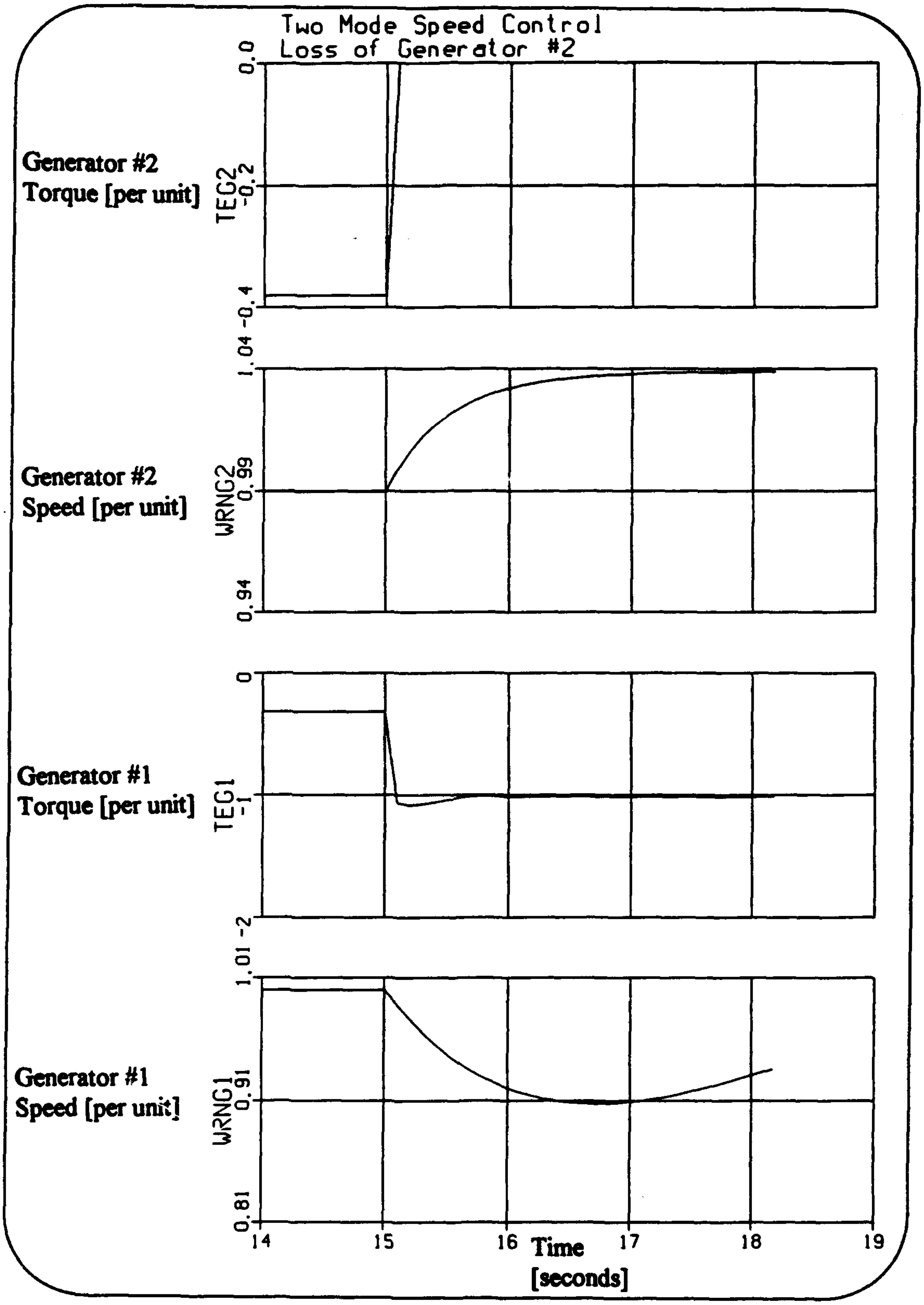


Figure 5-3 (continued)



Two Mode Speed Control
Loss of Generator #2
Generator #2
Torque [per unit]
TEG2
0.0
-0.2
-0.4
Generator #2
Speed [per unit]
WRNG2
1.04
0.99
0.94
Generator #1
Torque [per unit]
TEG1
0
-1
-2
Generator #1
Speed [per unit]
WRNG1
1.01
0.91
0.81
14
15
16
17
18
19
Time
[seconds]

Figure 5-4

In the second run the speed is set to 0.9 per unit. Again, generator #2 is tripped off-line at T=15 seconds. In this case, the power demanded by the propulsion motor and ship's service load is greater than the capacity of generator #1. The torque trace in figure 5-4 shows the over-torque condition which results on generator #1. This over-torque condition causes a power turbine over-temperature shutdown of the gas turbine 3.18 seconds after the first generator failure. In this load condition, a one generator failure degrades into a two generator failure causing the entire ship to lose electrical power. This is obviously not an acceptable result. What is required to eliminate this problem is a supervisory control system which will monitor the on-line generating capacity and limit the maximum power demand of the propulsion motor to that which is available at any given instant in time. This will allow the ship to keep operating, albeit in a reduced capacity, when a generator failure occurs.

5.2 Features and Limitations of Simulation Models

There are several useful features to the simulation models developed in this research. First, they are highly portable. The only required hardware is a PC or a workstation. The software requirements are the ACSL program and a FORTRAN compiler. The ACSL translator writes FORTRAN-77 code which will compile on virtually any compiler. It should be noted that these systems do take a few hours to run on even the fastest PC's currently available. It is recommended that any future simulations done with these models be done on a workstation.

The models have been written in a modular object oriented fashion. This makes them quite flexible. Each physical component is written as a separate ACSL macro which allows the generation of unique variable names for each instance of a particular object. The control components are also in separate macros which readily allows evaluation of various control schemes without changing the basic configuration of the model.

Similarly, the interconnection equations have been solved to allow easy modification of the system. Any number of generators or loads can be added to the main bus by simply algebraically adding its current to equations (3.23) & (3.24) and writing its transmission line equations, ((3.19) & (3.20) for generators or (3.21) & (3.22) for loads). Consequently, it is very easy to change the configuration of the simulation model. Only a knowledge of Kirchoff's laws and a minimal understanding of ACSL syntax is required to modify the system to suit the users needs.

There are also some limitations to the current models. The frequency changer model doesn't have a discontinuous current mode of operation. As mentioned previously, when the motor speed drops below about 10% of rated, the back EMF isn't sufficient to cause commutation of the inverter thyristers. This has been ignored in the current model. One method of simulating discontinuous conduction in an average value model presented by Branson [12] makes the dc-link current follow a rectified sine wave.

Another limitation to the current models is the diesel engine. It has not been properly verified against test data for the actual engine. Despite numerous efforts, the author has been unable to obtain dynamometer data for the particular engine which has been modeled. The computer model has been qualitatively compared to actual data of

other engines, but a quantitative comparison can only be made against the engine on which the engine map is based.

The ship load dynamic model could be improved. It is only a one dimensional model, whereas ship motions have six degrees of freedom. The model allows two propeller shaft inputs, but since it is one dimensional, operating the two shafts at different speeds only results in an averaged speed output. This can be seen in the outputs of the two motor simulations in appendix C. In an actual ship, this type of operation would generate a yawing moment causing the ship to turn left or right. The seaway feature of this model could also be improved upon. A real seaway is random in nature, containing many harmonic components. Many of these components will not excite the propulsion system, however some sort of random distribution of wave frequency would be an improvement on the current model.

5.3 Suggestions for Future Research

Quantitatively verify the diesel engine model. This may require switching the model to a different engine. The particular engine chosen for this study was selected because it is a Navy qualified diesel generator set currently in use aboard ships. Perhaps a manufacturer who is not yet Navy qualified would be more forthcoming with their test data.

Add a discontinuous conduction mode to the frequency changer model. Similarly, including the effects of AC-side reactance which were ignored in the development of the current model would be more realistic. AC-side reactance is always present when

connected to a motor load. Bose [9] presents this concept, but does not utilize it in the development of average value converter models for control studies.

The controls which have developed to date are rather rudimentary. More sophisticated controls incorporating the supervisory features discussed above should be developed. The concepts of graceful degradation and damage tolerant controls should also be investigated.

5.4 Conclusions

This research has developed and demonstrated useful tools for the design of controls for shipboard electrical systems. By taking an object oriented approach, the resulting tools are very flexible and can be used to simulate any conceivable shipboard configuration with only minor alterations. As a result the "learning curve" for an engineer not familiar with the specifics of ACSL or the various devices is greatly reduced.

The current model parameters are based on the U.S. Navy's "Baseline 2" electric drive system which utilizes wound rotor synchronous machine technology. The flexibility of these simulation models allows other technologies such as permanent magnet or superconducting machines to be simulated with minimal changes to the model.

This research has also conducted a preliminary control analysis of the required control systems. It has pointed out areas where more sophisticated controls are required and areas where existing controls may be adequate. The controls engineer interested in this specific problem now has a flexible tool which may be used to evaluate many sorts of control systems, only some of which have been discussed herein.

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Appendix A: ACSL Code

A.1 System #1

```
!=================================================================
!
!                 System 1: single generator
!               with ship dynamics and ship service loads
!
!                 Copyright 1993 by Timothy J. McCoy
!
!*****************************************************************
!       NOTE:   this model requires the following compiler
!               command line options:  "/AH /B1 f1l.exe"
!*****************************************************************
!
!       NOTE:   The gas turbine and ship dynamics models require
!               the following function lookup subroutines:
!                       fcq.for,func.for,qlapsf.for,qlavsf.for,
!                       qlavsr.for,tlavsf.for,tlavsr.for
!
!               These subroutines are property of the U.S. Navy and
!               can be obtained by qualified users from code 2753 of
!               NSWC Annapolis Detachment (Formerly DTRC-Annapolis).
!
!=================================================================
!
!                            RECORD OF CHANGES
!
!   NO. DATE     BY      SUMMARY
!   --- ------   ---     ----------------------------------------
!    0  4-10-93  tjm     Model Written.
!=================================================================
PROGRAM system1
!=================================================================
!                            MACRO DEFINITIONS
!=================================================================
INCLUDE 'c:\acsl\synmac\synmtr4.mac'
INCLUDE 'c:\acsl\synmac\synmtr4b.mac'
INCLUDE 'c:\acsl\freqchg\freqchg2.mac'
INCLUDE 'c:\acsl\synmac\vreg2.mac'
INCLUDE 'c:\acsl\synmac\contmtr.mac'
INCLUDE 'c:\acsl\synmac\spdcon3.mac'
INCLUDE 'c:\acsl\misc\constant.inc'
INCLUDE 'c:\acsl\lm2500\turbine.mac'
INCLUDE 'c:\acsl\ship\ship.mac'
INCLUDE 'c:\acsl\loads\shipserv.mac'
INCLUDE 'c:\acsl\misc\baseconv.mac'
!=================================================================
!                            INITIAL SECTION
!=================================================================
INITIAL
    SORT
```

```
!---Set base frequency & bus parameters
CONSTANT wo     = 377.0 !---[rad/sec]
CONSTANT xgl    = 0.1, &
         xll    = 0.1, &
         xml    = 0.1

!---Set parameters for dynamic brake
LOGICAL lbrake
    lbrake  = .false.
    kbrake  = 1.0
    gml     = 1.5

!---Set frequency changer parameters
    LOGICAL  lfwdl
    lfwdl   = .true.

!---Set synchronous motor parameters (20,000 HP 150 RPM motor)
!---24 poles
CONSTANT  &
    xqml     = 1.157,&
    xdml     = 1.76 ,&
    xqppml   = 0.494,&
    xdppml   = 0.542,&
    xdpml    = 0.608,&
    xlml     = 0.337,&
    tdopml   = 2.10 ,&
    tdoppml  = 0.039,&
    tqoppml  = 0.193,&
    basenml  = 150  ,&
    basevml  = 5000 ,&
    basekwml = 14914.0

    hml      = 0.773 + hhps !---hhps is propeller/shaft inertia
    baseqml  = 1000*basekwml/(basenml/rpmrad)

    xdmxqml  = xdml - xqml
!---Initialize the synchronous motors
    mtr4ic(ml)

!---Set synchronous generator parameters (18 MVA w h20 cooled stator)
!---values provided by NSWC
CONSTANT  &
    xqgl     = 1.64 ,&
    xdgl     = 1.77 ,&
    xqppgl   = 0.15 ,&
    xdppgl   = 0.15 ,&
    xdpgl    = 0.18 ,&
    xlgl     = 0.13 ,&
    tdopgl   = 3.19 ,&
    tdoppgl  = 0.04 ,&
    tqoppgl  = 0.09 ,&
    hgl      = 0.924,&
    basengl  = 3600.,&
    basevgl  = 4160.,&
```

```
    basekwg1 = 16200.0

!---conversion factors for generator and motor bases
    baseconv(kvg1m1,kkwg1m1,kig1m1,kzg1m1 = &
             basevg1,basevm1,basekwg1,basekwm1)

!---Initialize synchronous generators
    mtr4bic(g1)

!---Initialize gas turbine engine
    LOGICAL  lpwrd1               !---true for power demand mode
    CONSTANT lpwrd1 = .FALSE.  !---false for speed demand mode
    CONSTANT wrn1ord = 1.0      !---ordered speed [per unit]
    CONSTANT wrn1ordic = 1.0    !---ordered speed ic [per unit]
    CONSTANT teg1ic  = 0.0      !---electrical torque ic [per unit]
    CONSTANT wrng1ic = 1.0      !---generator speed ic [per unit]

!---set desired motor speed
    CONSTANT spdref1 = 1.0

END !---of initial
!=====================================================================
!                          DYNAMIC SECTION
!=====================================================================
DYNAMIC

    CINTERVAL   CINT  = .05       ! Communication interval
    NSTEPS      nstp  = 10
    MAXTERVAL   MAXT  = .1        ! Maximum integration step
    MINTERVAL   MINT  = 1.0E-8    ! Minimum integration step
    ALGORITHM   IALG  = 1         ! Integration algorithm
    CONSTANT    tstop = 0.0       ! stop time

!---stop on reaching maximum time
    TERMT(t.GE.(tstop-CINT/2.0),'====> STOP on time limit <====')

!=====================================================================
!                          DERIVATIVE SECTION
!=====================================================================
DERIVATIVE
!---Invoke synchronous generator macros
synmtr4b(teg1,vqg1,vdg1 = eafg1,iqg1,idg1,wrng1,g1)

!---Invoke voltage regulator macros
vreg2(eafg1 = vdg1,vqg1,g1)

!---Invoke Gas Turbine engine macro
turbine(1,lpwrd1,wrn1ord,wrn1ordic,teg1,teg1ic,wrng1ic,wrng1,qpt1pu)
wmg1  = wrng1*wo

!---Invoke synchronous motor macro
synmtr4 (tem1,vqm1,vdm1,wrnm1 = eafm1,iqm1,idm1,tmm1,m1)

!---Invoke motor controller macro
contmtr(eafm1,betai1 = idm1,iqm1,vdm1,vqm1,edppm1,eqppm1,&
```

```
        xdppml,xdmxqml,xqml,lbrake,ml)

!---Invoke frequency changer macro
freqchg (iqrl,idrl,iqil,idil = &
        vqrl,vdrl,vqil,vdil,idcrl,betail,lfwdl,lbrake,1)

!---Invoke speed controller macro
speedcon (idcrl,lfwdl,lbrake = spdrefl,wrnml,idcl,1)

!---Invoke ship load macro
wrnm2 = wrnml
ship(tmml,tmm2 = wrnml,wrnm2,basenml)

!---Invoke ship service load macro
shipserv(idl2,iql2 = vdbus,vqbus,1)

!---Transmission line equations
idgl    = (idrl + idl2)/kiglml
iqgl    = (iqrl + iql2)/kiglml
vdbus   = vdgl + iqrl*xgl
vqbus   = vqgl - idrl*xgl
vdrl    = vdbus + iqrl*xll
vqrl    = vqbus - idrl*xll
vdil    = vdml + iqml*xml
vqil    = vqml - idml*xml

!---This procedural places a braking resistor across motor terminals
!---when lbrake = .true.
PROCEDURAL (idml,iqml = idil,iqil,gml,lbrake)
    IF(lbrake)THEN
        IF(vtml.LT.0.3) gml = 5.0
        idbml    = vdml*gml
        iqbml    = vqml*gml
        idml     = idil + idbml
        iqml     = iqil + iqbml
    ELSE
        gml      = 1.5
        idbml    = 0.0
        iqbml    = 0.0
        idml     = idil
        iqml     = iqil
    ENDIF
END !---of procedural

END !---of derivative

END !---of dynamic
!=====================================================================
!                          TERMINAL SECTION
!=====================================================================
TERMINAL

END !---of terminal

END !---of program
```

A.2 System #2

```
!=====================================================================
!
!                   System 2a: two generators in parallel
!                 with ship dynamics and ship service loads
!
!                   Copyright 1993 by Timothy J. McCoy
!
!*********************************************************************
!        NOTE:   this model requires the following compiler
!                command line options:  "/AH /B1 fll.exe"
!*********************************************************************
!
!        NOTE:   The gas turbine and ship dynamics models require
!                the following function lookup subroutines:
!                        fcq.for,func.for,qlapsf.for,qlavsf.for,
!                        qlavsr.for,tlavsf.for,tlavsr.for
!
!                These subroutines are property of the U.S. Navy and
!                can be obtained by qualified users from code 2753 of
!                NSWC Annapolis Detachment (Formerly DTRC-Annapolis).
!
!=====================================================================
!
!                            RECORD OF CHANGES
!
!   NO. DATE     BY      SUMMARY
!   --- ------   ---     -----------------------------------------
!    0  4-10-93  tjm     Model Written.
!    1  4-10-93  tjm     Changed generator #1 to 2.5 MW kato unit.
!    2  4-10-93  tjm     Added gas turbine on generator #2.
!    3  4-10-93  tjm     Removed coordinate transfomation.
!    4  4-10-93  tjm     Added diesel engine to generator #1.
!    5  4-11-93  tjm     Acceleration run made. Changed name
!                        to 'system 2'
!    6  4-15-93  tjm     Switched speed control to 'spdcon2.mac'.
!    7  4-17-93  tjm     Added circuit breaker and breaking resistor
!                        to motor.  Changed name to "system2a"
!    8  4-18-93  tjm     Changed motor controller to "conmtr2".
!    9  4-19-93  tjm     Changed motor controller to "conmtr".
!   10  4-20-93  tjm     Successful crashback run. Changed TERMT
!                        statements to IF statements for applying
!                        dynamic brake resistor in 'spdcon3'.
!   11  4-20-93  tjm     Added circuit breaker to generator #2,
!                        Switched generator prime movers.
!=====================================================================
PROGRAM system2a
!=====================================================================
!                           MACRO DEFINITIONS
!=====================================================================
INCLUDE 'c:\acsl\synmac\synmtr4.mac'
INCLUDE 'c:\acsl\synmac\synmtr4b.mac'
INCLUDE 'c:\acsl\freqchg\freqchg2.mac'
```

```
INCLUDE 'c:\acsl\synmac\vreg2.mac'
INCLUDE 'c:\acsl\synmac\contmtr.mac'
INCLUDE 'c:\acsl\synmac\spdcon3.mac'
INCLUDE 'c:\acsl\misc\constant.inc'
INCLUDE 'c:\acsl\lm2500\turbine.mac'
INCLUDE 'c:\acsl\diesel\diesel.mac'
INCLUDE 'c:\acsl\diesel\governor.mac'
INCLUDE 'c:\acsl\ship\ship.mac'
INCLUDE 'c:\acsl\loads\shipserv.mac'
INCLUDE 'c:\acsl\misc\baseconv.mac'
INCLUDE 'c:\acsl\misc\cb.mac'
!=====================================================================
!                          INITIAL SECTION
!=====================================================================
INITIAL
    SORT

!---Set base frequency & bus parameters
CONSTANT wo     = 377.0 !---[rad/sec]
CONSTANT xg1    = 0.1, &
         xg2    = 0.1, &
         xl1    = 0.1, &
         xm1    = 0.1

!---Set parameters for dynamic brake
LOGICAL lbrake
    lbrake  = .false.
    kbrake  = 1.0
    gm1     = 1.5

!---Set frequency changer parameters
    LOGICAL  lfwd1
    lfwd1   = .true.

!---Set circuit breaker parameter
    LOGICAL  lcbg2
    CONSTANT lcbg2 = .true.  !---Initially close cbg2

!---Set synchronous motor parameters (20,000 HP 150 RPM motor)
!---24 poles
CONSTANT  &
    xqm1     = 1.157,&
    xdm1     = 1.76 ,&
    xqppm1   = 0.494,&
    xdppm1   = 0.542,&
    xdpm1    = 0.608,&
    xlm1     = 0.337,&
    tdopm1   = 2.10 ,&
    tdoppm1  = 0.039,&
    tqoppm1  = 0.193,&
    basenm1  = 150  ,&
    basevm1  = 5000 ,&
    basekwm1 = 14914.0

    hm1      = 0.773 + hhps !---hhps is propeller/shaft inertia
```

```
    baseqml   = 1000*basekwml/(basenml/rpmrad)

    xdmxqml   = xdml - xqml
!---Initialize the synchronous motors
    mtr4ic(ml)

!---Set synchronous generator parameters (18 MVA w h20 cooled stator)
!---values provided by NSWC
CONSTANT  &
    xqgl      = 1.64 ,&
    xdgl      = 1.77 ,&
    xqppgl    = 0.15 ,&
    xdppgl    = 0.15 ,&
    xdpgl     = 0.18 ,&
    xlgl      = 0.13 ,&
    tdopgl    = 3.19 ,&
    tdoppgl   = 0.04 ,&
    tqoppgl   = 0.09 ,&
    hgl       = 0.924,&
    basengl   = 3600.,&
    basevgl   = 4160.,&
    basekwgl  = 16200.0

!---Set synchronous generator parameters (kato 2.5 MW generator)
CONSTANT  &
    xqg2      = 1.01 ,&
    xdg2      = 1.63 ,&
    xqppg2    = 0.28 ,&
    xdppg2    = 0.18 ,&
    xdpg2     = 0.25 ,&
    xlg2      = 0.075,&
    tdopg2    = 3.79 ,&
    tdoppg2   = 0.38 ,&
    tqoppg2   = 0.19 ,&
    hg2       = 1.91 ,&
    baseng2   = 900.0,&
    basevg2   = 450.0,&
    basekwg2  = 2500.0

!---conversion factors for generator and motor bases
    baseconv(kvglml,kkwglml,kiglml,kzglml = &
             basevgl,basevml,basekwgl,basekwml)
    baseconv(kvg2ml,kkwg2ml,kig2ml,kzg2ml = &
             basevg2,basevml,basekwg2,basekwml)

!---Initialize synchronous generators
    mtr4bic(gl)
    mtr4bic(g2)

!---Initialize gas turbine engine
    LOGICAL  lpwrdl             !---true for power demand mode
    CONSTANT lpwrdl = .FALSE.   !---false for speed demand mode
    CONSTANT wrnlord = 1.0      !---ordered speed [per unit]
    CONSTANT wrnlordic = 1.0    !---ordered speed ic [per unit]
    CONSTANT teglic  = 0.0      !---electrical torque ic [per unit]
```

```
    CONSTANT wrnglic = 1.0     !---generator speed ic [per unit]

!---Initialize diesel engine
    CONSTANT cyl2    = 8       !---number of cylinders
    CONSTANT tmech2ic= 0.0     !---mechanical torque ic
    CONSTANT nmin2   = 400     !---min engine speed [rpm]
    CONSTANT nmax2   = 950     !---max engine speed [rpm]
    CONSTANT kturbo2 = 0.5     !---turbo constant [sec]
    CONSTANT wmg2ic  = 377.0   !---generator speed ic [rad/sec]

!---set desired motor speed
    CONSTANT spdref1 = 1.0

END !---of initial
!=====================================================================
!                              DYNAMIC SECTION
!=====================================================================
DYNAMIC

    CINTERVAL   CINT  = .05        ! Communication interval
    NSTEPS      nstp  = 10
    MAXTERVAL   MAXT  = .1         ! Maximum integration step
    MINTERVAL   MINT  = 1.0E-8     ! Minimum integration step
    ALGORITHM   IALG  = 1          ! Integration algorithm
    CONSTANT    tstop = 0.0        ! stop time

!---stop on reaching maximum time
    TERMT(t.GE.(tstop-CINT/2.0),'====> STOP on time limit <====')

!=====================================================================
!                              DERIVATIVE SECTION
!=====================================================================
DERIVATIVE
!---Invoke synchronous generator macros
synmtr4b(teg1,vqg1,vdg1 = eafg1,iqg1,idg1,wrng1,g1)
synmtr4b(teg2,vqg2,vdg2 = eafg2,iqg2,idg2,wrng2,g2)

!---Invoke voltage regulator macros
vreg2(eafg1 = vdg1,vqg1,g1)
vreg2(eafg2 = vdg2,vqg2,g2)

!---Invoke Diesel governor macro
governor(fuel2,n2 = wmg2,teg2,2)

!---Invoke Diesel engine macro
diesel(tmg2 = fuel2,n2,2)
wmg2d  = (teg2 + tmg2)*wo/(2*hg2)
wmg2   = INTEG(wmg2d,wmg2ic)
wrng2  = wmg2/wo

!---Invoke Gas Turbine engine macro
turbine(1,lpwrd1,wrnlord,wrnlordic,teg1,teg1ic,wrng1ic,wrng1,qpt1pu)
wmg1  = wrng1*wo
```

```
!---Invoke synchronous motor macro
synmtr4 (teml,vqml,vdml,wrnml = eafml,iqml,idml,tmml,ml)

!---Invoke motor controller macro
contmtr(eafml,betail = idml,iqml,vdml,vqml,edppml,eqppml,&
        xdppml,xdmxqml,xqml,lbrake,ml)

!---Invoke frequency changer macro
freqchg (iqrl,idrl,iqil,idil = &
         vqrl,vdrl,vqil,vdil,idcrl,betail,lfwdl,lbrake,1)

!---Invoke speed controller macro
speedcon (idcrl,lfwdl,lbrake = spdrefl,wrnml,idcl,1)

!---Invoke ship load macro
wrnm2 = wrnml
ship(tmml,tmm2 = wrnml,wrnm2,basenml)

!---Invoke ship service load macro
shipserv(idl2,iql2 = vdbus,vqbus,1)

!---Transmission line equations
CONSTANT vdbic  = 0.0, vqbic = 1.0, errbound = 0.0001,maxit = 10, &
         delv = 0.0001
IMPL(vdbus = vdbic,errbound,maxit,vderr,vdgl   + iqglml*xgl,delv)
IMPL(vqbus = vqbic,errbound,maxit,vqerr,vqgl   - idglml*xgl,delv)
IMPL(iqg2ml = iqg2ic,errbound,maxit,iqg2err,-(vdg2 - vdcbg2)/xg2,delv)
IMPL(idg2ml = idg2ic,errbound,maxit,idg2err,(vqg2 - vqcbg2)/xg2,delv)

!---Invoke circuit breaker macro for gen #2
cb(vdcbg2,vqcbg2,idcbg2,iqcbg2 = &
   lcbg2,vdbus,vqbus,vdg2,vqg2,idg2ml,iqg2ml)

idg2    = idg2ml/kig2ml
iqg2    = iqg2ml/kig2ml
CONSTANT kir = 2.0
idglml  = (kir*idrl + idl2 - idcbg2)
iqglml  = (kir*iqrl + iql2 - iqcbg2)
idgl    = idglml/kiglml
iqgl    = iqglml/kiglml
vdrl    = vdbus + iqrl*xll
vqrl    = vqbus - idrl*xll
vdil    = vdml + iqml*xml
vqil    = vqml - idml*xml

!---This procedural places a braking resistor across motor terminals
!---when lbrake = .true.
PROCEDURAL (idml,iqml = idil,iqil,gml,lbrake)
    IF(lbrake)THEN
        IF(vtml.LT.0.3) gml = 5.0
        idbml   = vdml*gml
        iqbml   = vqml*gml
        idml    = idil + idbml
        iqml    = iqil + iqbml
    ELSE
```

```
        gml     = 1.5
        idbml   = 0.0
        iqbml   = 0.0
        idml    = idil
        iqml    = iqil
    ENDIF
END !---of procedural

END !---of derivative

END !---of dynamic
!=====================================================================
!                         TERMINAL SECTION
!=====================================================================
TERMINAL

END !---of terminal

END !---of program
```

A.3 Diesel Engine

```
!---------------------------------------------------------------------
!
!                       Diesel Engine Model
!
!              Copyright 1992 by Timothy J. McCoy
!
!=====================================================================
!                         Record of Changes
!
! No.  Date     By      Summary
! ---  ------   ---     -----------------------------------------
!  0  12-20-92 tjm     Model written.
!  1  12-24-92 tjm     Changed input speed from rad/sec to rpm.
!=====================================================================
!   macro:     diesel
!   function:  Models four stroke turbocharged diesel engine.
!
!                            CONCATENATION
!       z         = synchronous machine identifier
!
!                               INPUTS
!       fr      = fuel rate [per unit]
!       n       = engine speed [rpm]
!
!                               OUTPUTS
!       tm      = mechanical torque [per unit]
!
!                              CONSTANTS
!=================(must be defined in the calling program)===========
!    tmech&z&ic  = mechanical torque ic [per unit]
!    cyl&z&      = number of cylinders [per unit]
!    nmin&z&     = minimum operating speed of engine [rpm]
!    nmax&z&     = maximum operating speed of engine [rpm]
```

```
!   kturbo&z&    = empirical turbo time constant [sec*p.u.torque]
!
!                      INTERNAL (STATE OR STATE RELATED)
!   fuelag&z&    = delay due to fuel rack and engine dynamics [sec]
!   turbolag&z& = delay due to turbocharger [sec]
!   delay&z&     = time constant of engine [sec]
!   Tmap         = lookup table of torque vs speed and fuel rate
!
!                        INTERNAL (NOT STATE RELATED)
!       NONE
!
!=====================================================================
!---include engine torque-speed look-up table
INCLUDE 'c:\acsl\diesel\cat3608.map'

MACRO diesel (tm , fr,n,z)
!=====================================================================
!                Begin Derivative Section
!=====================================================================

!---stop if engine is outside of performance limits
TERMT((n .LT. nmin&z&),'====> STOP Diesel engine underspeed <===')
TERMT((n .GT. nmax&z&),'====> STOP Diesel engine overspeed <===')

!---Calculate delay due to fuel injection and engine dynamics
fuelag&z&    = 30/n + 120/(cyl&z&*n)
!---Calculate delay due to turbo lag
turbolag&z& = kturbo&z&/(tm + 1)

!---Sum delays
delay&z&     = fuelag&z& + turbolag&z

!---Calculate torque from performance map lookup table
torq&z& = Tmap(fr,n)

!---Delay output of revised torque to account for engine dynamics
tm      = REALPL(delay&z&,torq&z&,tmech&z&ic)

!=====================================================================
!                End of Derivative Section
!=====================================================================
MACRO END ! of diesel
```

A.4 Diesel Engine Governor

```
!--------------------------------------------------------------------
!
!                          GOVERNOR MODEL
!
!                  Copyright 1992 by Timothy J. McCoy
!
!=====================================================================
!                         Record of Changes
!
```

```
! No.  Date     By      Summary
! ---  ------   ---     ------------------------------------------
!  0  12-22-92 tjm     Model written.
!  1  12-24-92 tjm     Added load torque compensation to the set
!                      speed.  Gain and time constant adjusted to
!                      their final values.
!  2  12-26-92 tjm     Added PID type control.
!  3  12-27-92 tjm     Added load compenstaton from generator voltages
!                      and currents.
!  4  12-28-92 tjm     Changed load compensation back to load torque
!                      as input.  Added wm as input and changed n to
!                      output for better modularity.
!  5  12-28-92 tjm     Revised constants for synchronous operation.
!                      Model verified.
!===================================================================
!   macro: governor.mac
!   function:  Limited PI type governor for a diesel engine
!
!                            CONCATENATION
!      z        = Engine identifier
!
!                              INPUTS
!      wm       = engine speed [rad/sec]
!      tl       = Load torque [per unit]
!
!                              OUTPUTS
!      fuel     = fuel rate [per unit]
!      n        = engine speed [rpm]
!
!                             CONSTANTS
!   kgov&z&     = governor gain
!   taugov&z&   = governor time constant
!   nset&z&     = desired engine speed [rpm]
!   fuelmin&z&  = minimum fuel rack setting [per unit]
!   fuelmax&z&  = maximum fuel rack setting [per unit]
!   k2gov&z&    = governor load factor gain
!
!================(must be defined in the calling program)==========
!
!                 INTERNAL (STATE OR STATE RELATED)
!
!                   INTERNAL (NOT STATE RELATED)
!      NONE
!
!===================================================================
MACRO governor (fuel,n,wm,tl,z)
!===================================================================
!               Begin Derivative Section
!===================================================================
!---parameters
   CONSTANT kgov&z&    = 0.2
   CONSTANT nset&z&    = 900.0
   CONSTANT taugov&z&  = 2.0
   CONSTANT fuel&min   = 0.0
   CONSTANT fuel&max   = 1.0
```

```
    CONSTANT fuel&ic    = 0.0

!---Convert speed to rpm for diesel use
    n = wm*2.38732 !---60/(2*pi*pole pairs)

!---Error signal
    spderr&z = nset&z - n

!---P-I type controller
!---fuel&d = (-fuel + pfac&z& + kgov&z*(spderr&z&))/taugov&z
!---fuel     = BOUND(fuel&min,fuel&max,LIMINT(fuel&d,&
!---           fuel&ic,fuel&min,fuel&max))

fuel = BOUND(fuel&min,fuel&max,kgov&z&*spderr&z& + &
       LIMINT(spderr&z&*kgov&z&/taugov&z&,fuel&ic,fuel&min,fuel&max))
!---P-I-D type controller
!---fuel     = BOUND(fuel&min,fuel&max,(kgov&z&*spderr&z &
!---          - LIMINT(fuel,fuel&ic,fuel&min,fuel&max))/taugov&z)
MACRO END !---of governor
```

A.5 Diesel Engine Map

```
!---Caterpillar 3608 performance map
!---Values are in per unit torque
!---Base torque is 17,973 ft-lbf.
!---speed is in RPM, Fuel rate is in per unit
!---Base fuel rate is 140 gal/hr.
TABLE Tmap, 2, 8,12/0.0,.1428,.2857,.4286,.5714,.7143,.8571,1.0,&
400.,450.,500.,550.,600.,650.,700.,750.,800.,850.,900.,950.,&
0.0, 0.1242, 0.1   , 0.04  , 0.053 , 0.014 , 0.017 , 0.003 , &
0.0, 0.1364, 0.2   , 0.08  , 0.105 , 0.029 , 0.035 , 0.007 , &
0.0, 0.1373, 0.3960, 0.16  , 0.21  , 0.058 , 0.069 , 0.015 , &
0.0, 0.1426, 0.4012, 0.31  , 0.42  , 0.115 , 0.139 , 0.031 , &
0.0, 0.1339, 0.3726, 0.6137, 0.8426, 0.23  , 0.278 , 0.062 , &
0.0, 0.1259, 0.3461, 0.5665, 0.7869, 0.46  , 0.555 , 0.125 , &
0.0, 0.1169, 0.3215, 0.5239, 0.7264, 0.9143, 1.1105, 0.25  , &
0.0, 0.1013, 0.2922, 0.4851, 0.6702, 0.8533, 1.0364, 0.5   , &
0.0, 0.0877, 0.2703, 0.4474, 0.6209, 0.7962, 0.9716, 1.0883, &
0.0, 0.0722, 0.2475, 0.4160, 0.5776, 0.7426, 0.9110, 1.0469, &
0.0, 0.0617, 0.2273, 0.3863, 0.5439, 0.6981, 0.8474, 1.0000, &
0.0, 0.0492, 0.2030, 0.3491, 0.4876, 0.6460, 0.7967, 0.9228/
```

A.6 Frequency Changer

```
!=====================================================================
!                Three phase frequency Changer model
!
!                          Copyright 1993
!                               by
!                        Timothy J. McCoy
!
!  Portions of this model are based on the models developed by
!  M. Branson et. al. of Purdue University for The U.S. Navy
!  DTRC code: 2753.  Used with permission.
!=====================================================================
```

```
!      NOTES: 1.)  This model assumes instantaneous commutation
!             2.)  all quantities are in per unit
!=====================================================================
!                              RECORD OF CHANGES
!
!   No.  Date      By    Summary
!   ---  ------    ---   --------------------------------------------
!    0   2-9-93    tjm   Model written
!    1   2-11-93   tjm   Removed one-phase portion of model
!    2   3-22-93   tjm   Added betai to input list for controller use
!=====================================================================
!   macro:       freqchg
!   function:    models a three phase dc-link frequency converter
!
!                              CONCATENATION
!  z          =    frequency changer identifier
!
!                              INPUTS
!  vqr        =    the machine-side, q-axis voltage of rectifier
!  vdr        =    the machine-side, d-axis voltage of rectifier
!  vqi        =    the machine-side, q-axis voltage of inverter
!  vdi        =    the machine-side, d-axis voltage of inverter
!  idcr       =    commanded value of dc link current
!  betai      =    inverter firing angle [rad]
!  lfwd       =    logical variable to determine direction of
!                  desired torque
!
!                              OUTPUTS
!  iqr        =    the machine-side, q-axis current of rectifier
!  idr        =    the machine-side, d-axis current of rectifier
!  iqi        =    the machine-side, q-axis current of inverter
!  idi        =    the machine-side, d-axis current of inverter
!
!                              CONSTANTS
!                  Defined in 'constant.inc'
!  k3rt3opi =      1.65398669   = 3*sqrt(3)/pi
!  krt3       =    1.732050808 = sqrt(3)
!  k2rt3opi =      1.10265779   = 2*sqrt(3)/pi
!  k2ort3     =    1.154700538 = 2/sqrt(3)
!
!                          INTERNAL (STATE OR STATE RELATED)
!  er&z&      =    Rectifier AC side voltage magnitude
!  ei&z&      =    Inverter AC side voltage magnitude
!  delr&z&    =    Reciifier AC side voltage angle
!  deli&z&    =    Inverter AC side voltage angle
!  idc&z&     =    DC link current
!  idc&z&d    =    DC link current derivative
!  betar&z    =    firing angle for rectifier
!  vr&z       =    link-side rectifier voltage
!  vi&z       =    link-side inverter voltage
!
!                          INTERNAL (NOT STATE RELATED)
!
!                              MACROS
!  rcc         =   establish rectifier control angles
```

```
!-----------------------------------------------------------------"
INCLUDE 'c:\acsl\freqchg\rcc.mac'

MACRO freqchg(iqr,idr,iqi,idi , &
              vqr,vdr,vqi,vdi,idcr,betai,lfwd,lbrake,z)

!--- DC link parameters
    CONSTANT xdc&z&   = 1.68          !---DC rectance [per unit]
    CONSTANT rdc&z&   = 0.02          !---DC resistance [per unit]
    CONSTANT idc&z&ic = 0.0           !---DC current ic [per unit]

!---Invoke rcc to define rectifier current control angle
    rcc(betar&z = idc&z&,idcr,lbrake,z)

!---Establish the rectifier ac currents (iqr,idr)
    iqr      = k2rt3opi*idc&z&*COS(betar&z&)
    idr      = k2rt3opi*idc&z&*SIN(betar&z&)

!---Establish the inverter ac currents (iqi,idi)
IF(lfwd) THEN
    iqi      = k2rt3opi*idc&z&*COS(betai)
    idi      = k2rt3opi*idc&z&*SIN(betai)
ELSE
    iqi      = -k2rt3opi*idc&z&*COS(betai)
    idi      = k2rt3opi*idc&z&*SIN(betai)
ENDIF

!---Establish the rectifier dc side voltage
    RTP(er&z&,delr&z& = vqr,vdr)
    vr&z&    = k3rt3opi*er&z&*COS(betar&z&)

!---Establish the inverter dc side voltage
    RTP(ei&z&,deli&z& = vqi,vdi)
    vi&z&    = k3rt3opi*ei&z&*COS(betai)

!---Establish the DC-LINK Current
    idc&z&d = wo/xdc&z&*(vr&z& + vi&z& - rdc&z&*idc&z&)
    idc&z&  = INTEG(idc&z&d,idc&z&ic)

MACRO END
```

A.7 Rectifier Current Controller

```
!=================================================================
!
!                   DC-LINK CURRENT CONTROL MODEL
!
!                         Copyright 1992
!                               by
!                        Timothy J. McCoy
!
!=================================================================
!
!    macro:     rcc
!    function:  rectifier current control, P-I type controller.
```

```
!
!                               CONCATENATION
!   z           =  frequency changer identifier
!
!                               INPUTS
!   idc         =  dc link current  [PER UNIT]
!   idcr        =  dc link reference current  [PER UNIT]
!
!                               OUTPUTS
!   betar       =  dc-link current control angle
!
!                               CONSTANTS
!   gbetar&z&   = Controller Amplitude
!   tubetar&z&  = Controller Time Constant
!   umin&z&     = minimum rectifier angle (maximum current)
!   umax&z&     = maximum rectifier angle (minimum current)
!
!                               INTERNAL
!   u&z&ic      = rectifier control angle ic
!   u&z&d       = rectifier control angle derivative
!   ierr&z&     = dc link current error
!======================================================================

MACRO rcc (betar , idc,idcr,lbrake,z)

CONSTANT umin&z&    = -0.0
CONSTANT umax&z&    =  0.99
CONSTANT gbetar&z&  = 30.0
CONSTANT taubetar&z =  0.01
CONSTANT u&z&ic     =  0.0
CONSTANT ierr&z&ic  =  0.0

ierr&z = (idcr - idc)
u&z&d  = (-u&z& + gbetar&z&*(ierr&z&))/taubetar&z
u&z&   = BOUND(umin&z&,umax&z&,LIMINT(u&z&d,u&z&ic,umin&z&,umax&z&))

IF(lbrake)THEN
    betar  = kpio2
ELSE
    betar  = ACOS(u&z&)
ENDIF

MACRO END !---of rcc
```

A.8 Induction Motor

```
!|-------------------------------------------------------------------|
!|                                                                   |
!|              THREE-PHASE INDUCTION MACHINE MODEL                  |
!|                                                                   |
!|              Copyright 1992 by Timothy J. McCoy                   |
!|                                                                   |
!|-------------------------------------------------------------------|
!
!======================================================================
!                         Record of Changes
```

```
!
!   No. Date      By     Summary
!   --- ------    ---    ------------------------------------------
!   0.  11-16-92  tjm    Model written.
!   1.  11-29-92  tjm    Included stator transients to eliminate
!                        algebraic loop problem.
!
!   2.  11-30-92  tjm    MODEL VERIFIED.
!==================================================================
!
!    macro:      indmac
!    function:   Models a symmetrical three-phase induction machine

!                with stator electric transients included.
!
!                               CONCATENATION
!       z        = synchronous machine identifier
!
!                                 INPUTS
!       vd       = D-axis terminal voltage [per unit]

!       vq       = Q-axis terminal voltage [per unit]
!       tm       = Mechanical Torque [per unit]
!
!                                 OUTPUTS
!       wrn      = Machine speed [per unit]
!       iqs      = Q-axis terminal current [per unit]
!       ids      = D-axis terminal current [per unit]
!
!                                CONSTANTS
!       wb       = base electrical speed [rad/sec]
!       rs&z     = Stator winding resistance [per unit]
!       rr&z     = Rotor winding resistance [per unit]
!       xm&z     = Stator to rotor mutual reactance [per unit]
!       xls&z    = Stator winding leakage reactance [per unit]
!       xlr&z    = Rotor winding leakage reactance [per unit]
!       h&z      = Rotor inertia [sec]
!       xaq&z&   = reactance used in calculating mutual coupling flux
!
!                        INTERNAL (STATE OR STATE RELATED)
!       siqs&z&d = rates of change of stator flux linkages [per unit]
!       sids&z&d
!       siqs&z   = Q-axis stator flux linkage [per unit]

!       sids&z   = D-axis stator flux linkage [per unit]
!       siqr&z&d = rates of change of rotor flux linkages
!       sidr&z&d
!       siqr&z   = Q-axis rotor flux linkage [per unit]
!       sidr&z   = D-axis rotor flux linkage [per unit]
!       simq&z   = Q-axis mutual coupling flux
!       simd&z   = D-axis mutual coupling flux
!       wm&z     = rotor speed [rad/sec]
!       wm&z&d   = rate of change of rotor speed [rad/sec^2]
!       iqr&z    = Q-axis rotor current [per unit]
!       idr&z    = D-axis rotor current [per unit]
```

```
!
!                      INTERNAL (NOT STATE RELATED)
!       siqr&z&ic = rotor flux linkage ics [per unit]
!       sidr&z&ic
!       siqs&z&ic = stator flux linkage ics [per unit]
!       sids&z&ic
!       wm&z&ic   = rotor mechanical speed ic [rad/sec]
!=====================================================================

MACRO indmac (z,tm,wrn,iqs,ids,vq,vd)

INITIAL

!---set initial rotor speed and fluxes to zero
       CONSTANT wm&z&ic   = 0.0
       CONSTANT siqr&z&ic = 0.0
       CONSTANT sidr&z&ic = 0.0

       siqs&z&ic = vd
       sids&z&ic = vq

!---compute reactance used in calculating mutual flux
       xaq&z&   = 1/(1/xm&z& + 1/xls&z& + 1/xlr&z&)

END !---of initial section

!=====================================================================
!                 Begin Derivative Section
!=====================================================================
!---mutual coupling flux
       simq&z&  = xaq&z&*(siqs&z&/xls&z& + siqr&z&/xlr&z&)
       simd&z&  = xaq&z&*(sids&z&/xls&z& + sidr&z&/xlr&z&)

!---Rates of Change of stator flux-linkages
       siqs&z&d = wb*(vq - rs&z&*iqs - sids&z&)
       sids&z&d = wb*(vd - rs&z&*ids + siqs&z&)

!---Rates of Change of rotor flux-linkages
       siqr&z&d = -(wb - wm&z&)*sidr&z& + &
                            wb*(rr&z&/xlr&z&)*(simq&z& - siqr&z&)
       sidr&z&d =  (wb - wm&z&)*siqr&z& + &
                            wb*(rr&z&/xlr&z&)*(simd&z& - sidr&z&)

!---Mechanical equation
       wm&z&d   = (te&z& - tm)*wb/(2*h&z&)

!---integrate state equations to obtain flux linkages & rotor speed
       siqr&z&  = INTEG(siqr&z&d,siqr&z&ic)
       sidr&z&  = INTEG(sidr&z&d,sidr&z&ic)
       siqs&z&  = INTEG(siqs&z&d,siqs&z&ic)
       sids&z&  = INTEG(sids&z&d,sids&z&ic)
       wm&z&    = INTEG(wm&z&d,wm&z&ic)

!---Compute stator currents in terms of fluxes
       iqs      = (siqs&z& - simq&z&)/xls&z
```

```
        ids       = (sids&z& - simd&z&)/xls&z

!---Compute Electromagnetic Torque
        te&z&     = (sids&z&*iqs - siqs&z&*ids)

!---Compute per unit mechanical speed
        wrn       = wm&z&/wb

!=====================================================================
!                  End of Derivative Section
!=====================================================================

MACRO END ! of indmac
```

A.9 Gas Turbine

```
!=====================================================================
!
!                     LM-2500 Gas Turbine Generator macro
!                     Copyright 1993 by Timothy J. McCoy
!
!---------------------------------------------------------------------
!
!NOTE:   The macros used in this model were provided by CODE: 2753 of
!        NSWC Annapolis and are used with permission. Only minor
!        changes were made to allow the model to run on a PC.
!
!---------------------------------------------------------------------
!*********************************************************************
!        NOTE:   this model requires the following compiler
!                command line options:  "/Zi /AH /Bl fl1.exe"
!                and linker command line options:  "/CO"
!*********************************************************************
!
!=====================================================================
!
!                            RECORD OF CHANGES
!
!   NO. DATE      BY      SUMMARY
!   --- ------    ---     ----------------------------------------
!    0  4-05-93   tjm     Model Written.
!=====================================================================
!                            MACRO DEFINITIONS
!=====================================================================
INCLUDE 'c:\acsl\lm2500\LM25a.mac'
INCLUDE 'c:\acsl\lm2500\tgid2.mac'
INCLUDE 'c:\acsl\lm2500\LM25crpm.mac'
!=====================================================================
!                            CONCATENATION
!    z           concatenation variable
!
!                            INPUTS
!    lpwrdz   = true for constant power mode
!               false for constant speed mode
!    wrnzord  = ordered speed in pu
!    wrnzordi = ordered speed ic in pu
```

```
!     tez       = synchronous machine torque in pu
!     tezi      = synchronous machine torque ic in pu
!     wrnzi     = synchronous machine speed ic
!
!                         OUTPUTS
!     wrnz      = synchronous machine speed
!     qptzpu    = per unit turbine torque on generator base
!=====================================================================
!---The following constants apply to all turbines defined
!---by following macro model
CONSTANT jjg = 16505       ! generator inertia in lbm-ft^2
CONSTANT ngb = 3600        ! generator base rpm
CONSTANT qgb = 36.52e3     ! generator base torque
!---invoke miscellaneous constants macro
    LM25mc0(ki,kqhp,kgc,p2,t2,theta2,sqrth2,thta2v,thet2n,delta2)

MACRO turbine(z,lpwrdz,wrnzord,wrnzordi,tez,tezi,wrnzi,wrnz,qptzpu)

INITIAL
    CONSTANT hp&z&ordi = 0.0          ! ordered turbine hp ic
    tesm&z&i = -tezi*qgb              ! convert from pu to ft-lbf
    n&z&i = wrnzi*ngb                 ! convert from rpm to pu
    hp&z&i = n&z&i*tesm&z&i/kqhp      ! generator hp
    npt&z&ordi = wrnzordi*npt&z&b     ! convert from pu to rpm

END !---of initial

!---Invoke load interface macro
tgid2(z, qpt&z&, jjpt&z&, npt&z&b, qpt&z&b, tesm&z&i, tesm&z&, &
     jjg, ngb, n&z&i, dnpt&z&, npt&z&, npt&z&i,qpt&z&i, dn&z&, n&z&)

!---Invoke throttle input command macro
LM25crpm4(z, npt&z&b, npt&z&ord, npt&z&ordi, npt&z&i, npt&z&,   &
          hp&z&b, hp&z&, hp&z&i, hp&z&ord, hp&z&ordi, lpwrdz,   &
          tic&z&ul, tic&z&ll, ticmd&z&, ticmd&z&i)

!---Invoke gas gen/ power turb macro
LM25gt0(z, t2, delta2, sqrth2, thet2n, thta2v, ki, kgc, &
       Farg0, Fargl, tic&z&, wfuel&z&, &
       npt&z&i, qpt&z&i, ngg&z&i, jjpt&z&, ps3&z&, ps3&z&i, &
       p54&z&, p54&z&i, wfuel&z&i, ngg&z&, npt&z&, npt&z&b, &
       qpt&z&, qpt&z&b, hp&z&b)

!---Invoke power lever angle macro
fsee0(z, p2, t2, ticmd&z&, npt&z&, npt&z&i, p54&z&, &
      p54&z&i, ticmd&z&i, alpha&z&i, tic&z&, alpha&z&,nref&z&)

!---Invoke main fuel control macro
mfc0(z, t2, thet2n, sqrth2, alpha&z&, ngg&z&, ps3&z&, &
     Farg0, Fargl, ngg&z&i, ps3&z&i, wfuel&z&i,alpha&z&i, wfuel&z&)

!---convert from pu to ft-lbf
tesm&z& = -tez*qgb

!---convert from rpm to pu
```

```
wrnz    = n&z&/ngb

!---convert from pu to rpm
npt&z&ord = wrnzord*npt&z&b

!---generator hp
hp&z& =  n&z&*tem&z&/kqhp

!---ordered turbine hp in power demand mode
CONSTANT hp&z&ord = 0.0

!---turbine torque in pu on gen base
qptzpu = qpt&z * (npt&z&b/ngb) /qgb

MACRO END !---of turbine.mac
!============================ LM25mac0.mod ========================
!------------------------------------------------------------------
!   file name:  LM25mac0.mod    clp     8-apr-91     v-1g92-0
!------------------------------------------------------------------
!
!   This model is a MACRO representation of an LM2500 gas turbine
!   engine that has been developed to permit cloning in simulations
!   requiring two or more LM2500 engines. The LM2500 consists of
!   four parts:(1) a Power Lever Angle Controller (FSEE), (2) a
!   Main Fuel Controller (MFC), (3) a Gas Generator, and (4) a Power
!   Turbine.  For convenience, separate MACROs have been developed
!   for the FSEE and the MFC to permit substituting other control
!   system models as the need arises.  In all, four MACROs have
!   been developed as listed below:
!
!      (1) LM25mc0.mac ---- Defines miscellaneous constants
!              specific to the LM2500 model.
!
!      (2) fsee0.mac ------ Characterizes the Power Lever Angle
!              Controller used with the LM2500 model.
!
!      (3) mfc0.mac ------- Characterizes the Main Fuel Controller
!              used with the LM2500 model.
!
!      (4) LM25gt0.mac ---- Characterizes the Gas Generator and
!              Power Turbine portion of the LM2500
!              model.
!
!   This model has been extracted from the program IED_FULL_1.CSL
!   developed by PDI Corp. for DTRC Code 2753 and reported in
!   reference [1] below.   The simulation developed in reference [1]
!   used reference [2] for the FSEE and MFC models, reference [3]
!   for the Gas Generator and Power Turbine Dynamics Models, and
!   reference [4] for the Alarms and Simulation Shutdown features.
!
!   This model requires the following files which contain function
!   data and the necessary lookup routines:
!
!     /models/LM2500/fun/data/LM25lib1.a
!     /models/lookup/lookuplib.a
```

```
!
!   In addition to the basic model changes needed to develop the
!   appropriate MACROs, the following changes have been made to
!   simplify the model:
!
!      (1)  Use PDI simplification of FSEE for the high frequency,
!           nonlinear loop [ thdot2 = f(e23,snegvl) ]; that is,
!           substitute IED_REDUCED_1.CSL code from page C-9 of
!           reference [1] for IED_FULL_1.CSL code on page B-9 used
!           to calculate alpha.
!
!      (2)  Further simplify FSEE model by eliminating the thetam
!           calculation by adjusting the limits on the LIMINT
!           for alpha, then eliminate the calculation of e2 and
!           adjust the calculation of e21.  This modification has
!           been taken from work reported in reference [5].
!
!      (3)  Modify the MFC model to simplify afl, dfl, afrl, dfrl,
!           emffb, and xmv circuit calculations.  This modification
!           has been taken from work reported in reference [5].
!
!   Simulation validation runs were made to examine the gas turbine
!   response for the above modifications.  The results indicated
!   that the modifications had negligible effect on the overall
!   transient response of the gas turbine.  Any further changes,
!   corrections, or modifications to this model should be noted in
!   the CHANGE RECORD started below:
!
!=====================================================================
!
!  MODELING CONVENTIONS:
!  --------------------
!
!  (1)  Use CAPS for ACSL statements, ACSL variables, etc.
!
!  (2)  Use lower case for all model variables.
!
!  (3)  Begin Table names, Function names and related control
!   variables with a capital letter.
!
!=====================================================================
!
!  MODEL REFERENCES:
!  ----------------
!  [1]  Mathematical Models and ACSL Simulation of the Integrated
!       Electric Drive Study Ship, LM2500 Gas Turbine and Gas
!       Turbine Control System, PDI Corp. Report 324-041-02,
!       June 1990.
!
!  [2]  LM2500 Simplified Non Linear Engine and Control System
!       Simulation, General Electric Marine and Industrial Projects
!       Department, G. E. Document  MID-TD-2500-13, January 1978,
!       Revised April 1978.
!
!  [3]  LM2500 Nonlinear Simplified Engine Model for IEC, General
```

```
!       Electric Marine and Industrial  Engine Projects Department,
!       G. E. Technical Memorandum 86-438, October 1986.
!
!  [4]  Propulsion Gas Turbine Module LM2500, Table  3.2-4,
!       Technical Manual S9234-AD-MMO-010/LM2500,  --  1 December
!       1977; and DD 963 Class Characteristics.
!
!  [5]  Simulation of a Superconductive Electric Drive for a
!   General Purpose Destroyer --- Part I:  Basic Approach to
!   Development of the Propulsion System Math Model, C. L.
!   Patterson and H. N. Robey, DTNSRDC Report TM-27-80-48,
!   submitted for distribution under cover letter 2711:HNR 3900
!   TM-27-80-48, dated 25 September 1980.
                                 !
!======================================================================
!
!  CHANGE RECORD:
!  -------------
!
! Version   Date    Engr   Description
! -------  -------  ----  -------------------------------------------
!    0     08apr91  clp   Model developed and installed.
!----------------------------------------------------------------------
!
!    1     18apr91  clp   Inserted new MACRO mfc0.mac with corrected
!                      afl&z& calculation
!
!    2     30apr91  clp   Replace LM25gt0.mac and fsee0.mac with
!                      corrected versions
!
!    3     16may91  clp   Replace fsee0.mac with modified version
!
!    4     30may91  clp   Uncommented TERMT statement to permit run
!                      to stop on kshtdn > 0 (TURBINE SHUTDOWN),
!                      and added TERMT on ktbl > 0 (TABLE OVERRUN)
!
!    5     01jul92  clp   Corrected decision logic coding of the ALARM
!                      and simulation SHUTDOWN section.
!
!======================================================================
!||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||
!----------------------------------------------------------------------
!
!  ================================================================
!  >>>>>>>>>>  Begin LM2500 Misc Constants Model MACRO  <<<<<<<<<<<
!  ================================================================

MACRO LM25mc0(ki,kqhp,kgc,p2,t2,theta2,sqrth2,thta2v,thet2n,delta2)

!   inputs:    NONE
!
!   outputs:  ki =  conversion factor for rotational accel
!            kgc = conversion factor for pounds mass to slugs
!           kqhp = conversion factor for torque/rpm to HP
!             p2 = compressor inlet pressure
```

```
!              t2 = compressor inlet total temperature
!          theta2 = temperature correction factor
!          sqrth2 = square root of theta2
!          thta2v =
!          thet2n = temperature correction factor
!          delta2 = ambient pressure correction factor

! ---------------- Define the ambient conditions

CONSTANT    tamb     = 59.0          ! --  degrees F
CONSTANT    pamb     = 14.696        ! --  PSIA

! ---------------- Define the conversion factor for rotational
!            acceleration calculations
!                 [ ki = (60.0 * kgc) / (2.0*pi) ]

CONSTANT    ki       = 307.24        ! -- lbm-rpm-ft/lbf-sec

! ---------------- Define the conversion factor for torque and rpm
!            to horsepower  [ kqhp = (60 * 550) / (2.0*pi) ]

CONSTANT    kqhp     = 5252.1        ! -- (ft-lbf/min)/hp

! ---------------- Define the conversion factor for pounds mass to
!            slugs (Gc)

CONSTANT    kgc      = 32.174        ! -- lbm-ft/lbf-sec**2

! +++++++ Begin INITIAL Section +++++++++++++++++++++++++++++++++++

!---INITIAL

! ---------------- Calculate temperature and pressure correction
!            factors.

p2        = pamb                     ! -- psia
t2        = tamb + 459.7             ! -- degrees R
theta2    = t2 / 518.7               ! -- nondimensional
sqrth2    = sqrt (theta2)            ! -- nondimensional
thta2v    = theta2 ** 1.00           ! -- nondimensional
thet2n    = theta2 ** 0.719          ! -- nondimensional
delta2    = p2 / 14.696              ! -- nondimensional

!---END !  ++++++++++++ of INITIAL

MACRO END

!>>>>>>>>>>>  End of LM2500 Misc Constants Model MACRO  <<<<<<<<<<<<
!-------------------------------------------------------------------
!
!  ==============================================================
!  >>>>>>>>>>>>>>>>>>  Begin FSEE Model MACRO  <<<<<<<<<<<<<<<<<<<<
!  ==============================================================
!   file name:  fsee0.mac   clp 8-apr-91
!
```

```
!   The power lever angle (PLA) controller (FSEE) model for the
!   LM2500 gas turbine. It has been developed based on references
!   [1],[2], and [5] of LM2500.ref.   It is essentially a MACRO
!       version of the model included in the simulation reported
!       in [1] with a few modifications based on [5].
!
!   This model requires the following files which contain
!   function data and the necessary lookup routines:
!
!       /models/LM2500/fun/data/LM25lib1.a
!       /models/LM2500/fun/data/lookuplib.a
!
! --------------------------------------------------------------
!  CHANGE RECORD:
!  -------------
!
! Version   Date    Engr    Description
! -------  -------  ----  ---------------------------------------
!    0     17apr91  clp   Model developed and installed.
!
!    1     30apr91  clp   Add tic to MACRO argument list and change
!                           all references to tic&z& to tic
!
!    2      2may91  clp   Modified MACRO argument list (added z's
!                           to most arguments)
!
!    3     16may91  clp   Change nref&z& to nrefz, add to argument
!                           list, and make appropriate code mods
!
!    4     02nov92  tjm   Added parenthesis in p2t2&z&i and qcal&z&i
!                           assignment statements to fix compiler error for PC use.
!
! ---------------------------------------------------------------

  MACRO  fsee0(z,p2,t2,ticmdz,nptz,nptzi,p54z,p54zi,ticmdzi, &
               alphazi,ticz,alphaz,nrefz)

!   inputs:        z = concatenation variable
!             p2 = compressor inlet pressure
!             t2 = compressor inlet total temperature
!         ticmdz = throttle input command from control system
!           nptz = power turbine shaft speed
!          nptzi = npt IC
!           p54z = power turbine inlet pressure
!          p54zi = p54 IC
!        ticmdzi = ticmd IC
!        alphazi = alpha IC
!
!   outputs:    ticz = bounded ticmdz
!         alphaz = rotary actuator position (actual TIC to MFC)

! ---------------- Power turbine torque limit -----
!                  (20000 <= qref <= 45000 lb-ft)
!                 (qref selected for vq=9.0 volts)
```

```
CONSTANT    qref&z&    = 45000   ! -- torque ref [lb-ft]
CONSTANT    vqsf&z&    = 5000    ! -- torq lim scale factor [lb-ft/volt]
CONSTANT    g1&z&      = 0.22    ! -- torque lim gain

! ---------------- Power turbine RPM limit -----
!                  (2800 <= nref <= 3900 rpm)
!              (nref selected for vr=7.344 volts)

CONSTANT    nrefz    = 3672    ! -- npt limit [rpm]
CONSTANT    vnsf&z&    = 500     ! -- npt lim scale factor [rpm/volt]
CONSTANT    g3&z&      = 0.5     ! -- npt limit gain

! ---------------- Power turbine RPM rate limit -----
!                  (dnref = 180 rpm/sec --- fixed)
!                (dnref selected for vr=0.5 volts)

CONSTANT    dnref&z&   = 180     ! -- npt rate lim [rpm/sec]
CONSTANT    vrsf&z&    = 360     ! --rate lim scale factor
[(rpm/sec)/volt]
CONSTANT    g5&z&      = 0.5     ! -- npt rate lim gain


! ---------------- Define upper/lower limits for the command input and
!                  the TIC rate limiter plus the gain for the rate
!           limiter

CONSTANT    tic&z&ul    = 113.5    ! -- command input UL and LL
CONSTANT    tic&z&ll    = 13.0     ! -- [degrees]

CONSTANT    ticrl&z&ul = 22.5     ! -- TIC rate limiter UL and LL
CONSTANT    ticrl&z&ll = -89.0    ! -- [deg/sec]
CONSTANT    krate&z&   = 10.      ! -- gain constant

! ---------------- Define upper/lower mechanical limits for alpha

CONSTANT    alpha&z&ul = 120.0    ! -- [degrees]
CONSTANT    alpha&z&ll = 13.0     ! -- [degrees]

! ---------------- Define the gain in the calculation of drpmdt

CONSTANT    krat&z&      = 0.16         ! -- nondimensional

! +++++++ Begin INITIAL Section +++++++++++++++++++++++++++++++++++
INITIAL
! ---------------- Calculate TIC rate-limited integrator output IC

ticrl&z&i    = BOUND ( tic&z&ll, tic&z&ul, ticmdzi )

! ---------------- Calculate reference voltages and ICs for power
!           turbine torque, RPM, and RPM rate limits

vq&z&       = (qref&z& / vqsf&z&)
vn&z&       = (nrefz / vnsf&z&)
vr&z&       = (dnref&z& / vrsf&z&)
```

```
!            ====> NOTE:  The p54zi calculation has been moved to the
!           LM25gt0 MACRO since that is where the function is
!           shown in references [1] and [2]

e0&z&i      = 0.0
p54l&z&i    = p54zi
p54ll&z&i   = p54l&z&i * 1.015
nptl&z&i    = nptzi
enpt&z&i    = nptl&z&i * 0.002
enptl&z&i   = enpt&z&i
p54q&z&i    = p54ll&z&i / p2
nptq&z&i    = nptl&z&i / sqrt(t2)
!
!           Put variables based on function lookups
!           in a PROCEDURAL
!
PROCEDURAL (qmap&z&i = p54q&z&i,nptq&z&i)
  qmap&z&i    = Fqmap(p54q&z&i, nptq&z&i)
END
!
!          End IC function lookup PROCEDURAL
!
qmapl&z&i   = qmap&z&i
p2t2&z&     = p2 * ( t2 ** (-0.157))
qcal&z&i    = (qmapl&z&i * p2t2&z&)
tabtr&z&i   = qcal&z&i * 0.0002 * ( 1 - .66 / .3 )
tglag&z&i   = enpt&z&i * (1.0 - (2.3 / .047))

END !---of initial

! +++++++ Begin DERIVATIVE Section +++++++++++++++++++++++++++++++++

! ---------------- Calculate and BOUND TIC

ticz    = BOUND ( tic&z&ll, tic&z&ul, ticmdz )

! ---------------- Calculate Rate Limited TIC

ticrl&z& =INTEG ( BOUND (ticrl&z&ll, ticrl&z&ul, &
            krate&z& * (ticz - ticrl&z&)), ticrl&z&i )

! ---------------- Calculate vtrqgs (torque limiting)

p54l&z&   = REALPL ( 0.014, p54z, p54l&z&i )
p54ll&z&  = REALPL ( 0.04, p54l&z& * 1.015, p54ll&z&i )
p54q&z&   = p54ll&z& / p2
nptl&z&   = REALPL ( 0.144, nptz, nptl&z&i )
nptq&z&   = nptl&z& / sqrt(t2)
qmap&z&   = Fqmap ( p54q&z&, nptq&z& )
qmapl&z&  = REALPL ( 0.03, qmap&z&, qmapl&z&i )
qcal&z&   = (p2 * (t2 ** (-0.157)) * qmapl&z&)
tabtrl&z& = LEDLAG ( 0.66, 0.3, qcal&z& * 0.0002 , tabtr&z&i )
e5&z&     = (vq&z& - tabtrl&z&)
delvtq&z& = BOUND ( -9999., 0.0, e5&z& )
vtrqgs&z& = (delvtq&z& * gl&z&)
```

```
! ---------------- Calculate vtop (topping governor)

enpt&z&   = (0.002 * nptl&z&)
tglag&z& = LEDLAG ( 2.3, 0.047, enpt&z&, tglag&z&i )
e7&z& = (vn&z& - tglag&z&)
e6&z& = BOUND ( -9999., 0.0, e7&z& )
vtop&z& = (e6&z& * g3&z&)

! ---------------- Calculate vrate (Acceleration Limiting)
!
!          Note that the next two lines match the block diagram
!          in effect but need to be expressed this way to handle
!          the initial conditions properly

        enptl&z&  = INTEG ( (enpt&z& - enptl&z&) / 0.04,enptl&z&i)
        drpmdt&z& = krat&z& * 4.7 * (enpt&z& - enptl&z& ) / 0.04
    e9&z& = (vr&z& - drpmdt&z&)
    e8&z& = BOUND ( -9999., 0.0, e9&z& )
    vrate&z& = (e8&z& * g5&z&)

! ---------------- Calculate snegvl

    snegvl&z& = MIN ( vtrqgs&z&, MIN ( vtop&z&, vrate&z&))

! ---------------- Calculate ALPHA (see notes at top on modifications
!                     to this section)

e21&z& = (ticrl&z& - alphaz) * 0.094066

PROCEDURAL ( xk31&z& = e5&z&, e7&z&)
  xk31&z& = 14.0
  IF ((e5&z& .LT. 0.35) .or. (e7&z& .LT. 0.35)) xk31&z& = 2.2
END

e22&z& = BOUND ( -14.0, xk31&z&, e21&z& * 60.0)

PROCEDURAL ( e23&z& = e5&z&, e7&z&, e9&z&, e22&z&)
  e23&z& = e22&z& / 3.0
  IF ((e5&z& .LT. 0.0) .or. (e7&z& .LT. 0.0) .or. (e9&z& .LT. 0.0)) &
        e23&z& = e22&z& / 40.0
END
PROCEDURAL ( thdot2&z& = e23&z& , snegvl&z& )
  IF ((e23&z& + snegvl&z&) .LT. -6.766 ) thdot2&z& = -131.646
  IF ((e23&z& + snegvl&z&) .GE. -6.766 &
        .AND. (e23&z& + snegvl&z&) .LT. -0.08445) &
        thdot2&z& = (93.0 * (e23&z& + snegvl&z&) + 7.854 ) / 4.72
  IF ((e23&z& + snegvl&z&) .GE. -0.08445  .AND. &
        (e23&z& + snegvl&z&) .LT.  0.08445) thdot2&z& = 0.0
  IF ((e23&z& + snegvl&z&) .GE.  0.08445  .AND. &
        (e23&z& + snegvl&z&) .LT.  1.316) &
        thdot2&z& = (93.0 * (e23&z& + snegvl&z&) - 7.854 ) / 4.72
  IF ((e23&z& + snegvl&z&) .GE.  1.316 .AND. &
        (e23&z& + snegvl&z&) .LT.  109.84) &
        thdot2&z& = (93.0 * (e23&z& + snegvl&z&) + 2159.42 ) / 94.0
```

```
  IF ((e23&z& + snegvl&z&) .GE.  109.84) thdot2&z& = 131.646
END

alphaz = LIMINT((57.3/55.64)*thdot2&z&,alphazi,alpha&z&ll,alpha&z&ul)

MACRO END

!  >>>>>>>>>>>>>>>>>>>  End of FSEE Model MACRO  <<<<<<<<<<<<<<<<<<<
!  ------------------------------------------------------------------
!
!  ================================================================
!  >>>>>>>>>>>>>>>>>>  Begin MFC Model MACRO  <<<<<<<<<<<<<<<<<<<
!  ================================================================
!   file name:  mfc0.mac    clp 9-apr-91
!
!   Main fuel controller model for the LM2500 gas turbine. It
!   has been developed based on references [1],[2], and [5] of
!   LM2500.ref.
!
!   This model requires the following files which contain
!   function data and the necessary lookup routines:
!
!       /models/LM2500/fun/data/LM25lib1.a
!       /models/LM2500/fun/data/lookuplib.a
!
!  ----------------------------------------------------------------
!  CHANGE RECORD:
!  -------------
!
! Version   Date    Engr    Description
! -------  -------  ----  ----------------------------------------
!    0     17apr91  clp   Model developed and installed.
!
!    1     18apr91  clp   Change wfueli to wfuel in afl&z&
!                calculation
!
!    2      2may91  clp   Modified MACRO argument list (added z's
!              to appropriate arguments)
!
! -----------------------------------------------------------------

MACRO  mfc0(z,t2,thet2n,sqrth2,alphaz,nggz,ps3z,Farg0,Farg1,nggzi, &
              ps3zi,wfuelzi,alphazi,wfuelz)

!   inputs:         z = concatenation variable
!                  t2 = compressor inlet total temperature
!              thet2n = temperature correction factor
!              sqrth2 = square root of theta2
!              alphaz = rotary actuator position (actual TIC to MFC)
!                nggz = gas generator speed
!                ps3z = compressor discharge static pressure
!               Farg0 = FORWARD lookup function interpolation flag
!               Farg1 = BACKWARD lookup fun interp (ARG 1 dependent)
!               nggzi = gas generator speed IC
!               ps3zi = compressor discharge static pressure IC
```

```
!        wfuelzi = wfuelz IC
!
!   outputs: alphazi = alpha IC
!         wfuelz = fuel flow rate

! ---------------- Declare array, variable and constant types

DIMENSION    mfw&z&(3)

! ---------------- Define some constants for the MFC model

CONSTANT    mfw&z&     = 159.4, 2091.3, 13659.6
CONSTANT    mfkac&z&   = 0.582
CONSTANT    mfkfr&z&   = 0.17259
CONSTANT    mfkmv&z&   = 23.0
CONSTANT    mfkn&z&    = 4.608E-8

! +++++++ Begin INITIAL Section +++++++++++++++++++++++++++++++++
INITIAL
! ---------------- Calculate MFC model ICs ====> NOTE:  the wfuelzi
!            and ps3zi calculations have been moved to the
!            LM25gt0 MACRO since that is where the functions
!            are shown in reference [1]

emffb&z&i    = 0.0
xmv&z&i      = BOUND ( 0.0, 1.0, (-mfw&z&(2) +  &
              sqrt(mfw&z&(2)**2.0 - 4.0*mfw&z&(3)*(mfw&z&(1)  &
                  - wfuelzi)))/(2.0*mfw&z&(3)))
arllg&z&i    = xmv&z&i
drllg&z&i    = xmv&z&i
ps3wc&z&i    = ps3zi
nggl&z&i     = nggzi
!
!            Put variables based on function lookups
!            in a PROCEDURAL
!
PROCEDURAL (alphazi = nggzi,Fargl)
  alphazi    = Ordngg( 0.0, nggzi,Fargl)
END !---End IC function lookup PROCEDURAL

END !---of initial

! +++++++ Begin DERIVATIVE Section ++++++++++++++++++++++++++++++++++

! ---------------- The MFC section has been modified to simplify the
!            calculation of AFL and DFL based on reference [5]

! ---------------- Demand gas generator speed

dngg&z&      = Ordngg (alphaz, 0.0, Farg0)

! ---------------- Error signal

engg&z&      = (mfkn&z&*((dngg&z&**2) - (nggz**2)) - emffb&z&)
emfsat&z&    = BOUND (dfl&z&, afl&z&, engg&z&)
```

```
erx&z&       = BOUND (dfrl&z&, afrl&z&, emfsat&z&)

! ---------------- Feedback signal (see pages C-2,8-9 and
!            figures 8-C and 9-C of reference [5])

emffb&z&     = REALPL(0.50,(11.5*erx&z&), emffb&z&i)
afrl&z&      = - (2.0 * emffb&z& - mfkfr&z&)
dfrl&z&      = - (2.0 * emffb&z& + mfkfr&z&)

! ---------------- Acceleration & deceleration limits (see pages
!            C-2,5 and figure 3-C of reference [5])

afl&z&       = (ALOG(wfac&z&/wfuelz) * mfkac&z&)
dfl&z&      = afl&z& - 0.93669

! ---------------- Calculate wfac

ps3wc&z&     = REALPL( 0.04, ps3z, ps3wc&z&i )
nggl&z&      = REALPL(0.04, nggz, nggl&z&i)
wfac&z&      = (Fwacc(nggl&z&/sqrth2, t2) * (thet2n) * ps3wc&z&)

! ---------------- Calculate fuel valve position and the fuel
!            as a function of position

xmv&z&       = (INTEG(2.0 * emffb&z&, xmv&z&i) + emffb&z&)

wfuelz   =   mfw&z&(3)*xmv&z&**2 + mfw&z&(2)*xmv&z& + mfw&z&(1)

MACRO END

!  >>>>>>>>>>>>>>>>>>>  End of MFC Model MACRO  <<<<<<<<<<<<<<<<<<<<
!  ------------------------------------------------------------------
!
!  ================================================================
!  >>>>>>  Begin Gas Generator and Power Turbine Model MACRO <<<<<<
!  ================================================================
!   file name:  LM25gt0.mac clp 9-apr-91
!
!   Gas generator and power turbine model for the LM2500 gas
!   turbine. It has been developed based on references [1],[2],
!   [3], and [4] of LM2500.ref.  It is essentially a MACRO
!       version of the model included in the simulation reported
!       in [1].
!
!   This model requires the following files which contain
!   function data and the necessary lookup routines:
!
!       /models/LM2500/fun/data/LM25libl.a
!       /models/LM2500/fun/data/lookuplib.a
!
!   It also needs the following parameters:
!
!            rpmrad, ftlbhp
!
!       from:  /home/ra4/patterson/acsl/constants.mod
```

```
!
! -------------------------------------------------------------
! CHANGE RECORD:
! ------------
!
! Version  Date     Engr  Description
! -------  -------  ----  --------------------------------------
!    0     17apr91  clp  Model developed and installed.
!
!    1     30apr91  clp  Add torque base (qptb) calculation
!
!    2      2may91  clp   Modified MACRO argument list (added z's
!             to appropriate arguments)
!
!    3     14may91  clp   Add horsepower base to MACRO argument list
!             as hpzb and make necessary code changes
!
! -------------------------------------------------------------


MACRO  LM25gt0(z,t2,delta2,sqrth2,thet2n,thta2v,ki,kgc,Farg0,Farg1, &
              ticz,wfuelz,nptzi,qloadi,nggzi,iptz,ps3z,ps3zi,p54z, &
              p54zi,wfuelzi,nggz,nptz,nptzb,qez,qptzb,hpzb)

!   inputs:        z = concatenation variable
!                 t2 = compressor inlet total temperature
!             delta2 = ambient pressure correction factor
!             sqrth2 = square root of theta2
!             thet2n = temperature correction factor
!                 ki = conversion factor for rotational accel
!                kgc = conversion factor for pounds mass to slugs
!              Farg0 = FORWARD lookup function interpolation flag
!              Farg1 = BACKWARD lookup fun interp (ARG 1 dependent)
!               ticz = throttle input command
!             wfuelz = fuel flow rate
!              nptzi = power turbine shaft speed IC
!             qloadi = qload IC
!
!   outputs:nggzi = gas generator speed IC
!               iptz = rotational inertia of power turbine
!               ps3z = compressor discharge static pressure
!              ps3zi = psi3 IC
!               p54z = power turbine inlet pressure
!              p54zi = p54z IC
!            wfuelzi = wf IC
!               nggz = gas generator speed
!               nptz = power turbine shaft speed
!              nptzb = power turbine shaft speed base RPM
!                qez = power turbine shaft output torque
!              qptzb = power turbine shaft base torque [LB-FT]

! ---------------  Declare array, variable and constant types

LOGICAL       lt54&z&a, lngg&z&a
```

```
INTEGER       kalarm&z&, kshtdn&z&, ktbl&z&

! ---------------- Define the difference between gas generator
!           turbine exhaust temperature (T51) and power
!           turbine inlet temperature (T54) as a function of
!           gas generator speed (NGG) and power turbine speed
!           (NPT) [DEG F].  See DHHs notes of 1/8/90 for the
!           source of this data

TABLE Tdt54&z&,2,6,6/                                        &
       0.0,  54.19,   76.32,   86.50,  96.67, 999999.0, &
       0.0,  500.0,  2000.0,  3000.0, 3960.0,  99999.0, &
      46.3,   46.3,    31.3,    47.3,   58.3,     58.3, &
      46.3,   46.3,    31.3,    47.3,   58.3,     58.3, &
      52.3,   52.3,    38.3,    50.3,   61.3,     61.3, &
      52.3,   52.3,    44.3,    55.3,   63.3,     63.3, &
      52.3,   52.3,    50.1,    61.3,   68.3,     68.3, &
      52.3,   52.3,    50.1,    61.3,   68.3,     68.3/

! ---------------- Define the power turbine speed setpoint
!           and the gas generator design rpm

CONSTANT    nptzb    = 3600.    ! -- power turbine rpm base
CONSTANT    hpzb     = 25000.0  ! -- power turb base horsepower
CONSTANT    ngg&z&b  = 9827.    ! -- gas gen design rpm base (100 pct)

! ---------------- Define the inertia of the gas generator rotor
!           This value is from LM25mac0.mod reference [2]

CONSTANT    igg&z&   = 566.7785   ! -- lbm-ft**2

! ---------------- Define the inertia of the power turbine.  Use
!           value specified by GE (via Lee Tupper)
!           (iptz= 1915 for validation check, see ref [2])

CONSTANT    iptz      = 2171.5     ! -- lbm-ft**2

! +++++++ Begin INITIAL Section ++++++++++++++++++++++++++++++++++++
INITIAL
! ---------------- Initialize alarm and shutdown parameters

lt54&z&a = .FALSE.
lngg&z&a = .FALSE.
kalarm&z& = 0
kshtdn&z& = 0

! ---------------- Calculate power turbine base torque

qptzb = (hpzb * ftlbhp * rpmrad) / nptzb

! ---------------- Calculate gas generator and power turbine
!           model ICs, p54zi for the FSEE model, and
!           ps3zi and wfuelzi for the MFC model

kpngg&z&   = (100.0 / ngg&z&b)
```

```
nptr&z&i    = nptzi / sqrth2
delwf&z&i   = 0.0
!
!           Put variables based on function lookups
!           in a PROCEDURAL
!
PROCEDURAL(pnggr&z&i,t4pl&z&i,t51pl&z&i,p54r2&z&i,ps3r2&z&i,wfuelzi &
             = nptr&z&i,delwf&z&i,qloadi,delta2,Fargl,thta2v,thet2n)

  pnggr&z&i  = Fdqp(0.0,nptr&z&i,delwf&z&i,qloadi/delta2,Fargl)
  t4pl&z&i   = Ft4(pnggr&z&i,nptr&z&i,delwf&z&i) * thta2v
  t51pl&z&i  = Ft51(pnggr&z&i,nptr&z&i,delwf&z&i) * thta2v
  p54r2&z&i  = Fp54(pnggr&z&i,nptr&z&i,delwf&z&i)
  ps3r2&z&i  = Fps3(pnggr&z&i,nptr&z&i,delwf&z&i)
  wfuelzi     = Fwfs(pnggr&z&i,nptr&z&i)* thet2n * delta2
END
!
!           End IC function lookup PROCEDURAL
!
nggzi        = (pnggr&z&i / kpngg&z& ) * sqrth2
p54zi        = p54r2&z&i * delta2
ps3zi        = ps3r2&z&i * delta2
END !---of initial

! +++++++ Begin DERIVATIVE Section ++++++++++++++++++++++++++++++++

! ----------------  GAS GENERATOR SECTION  -------------------------

! ----------------  Calculate delwf

wfsr2&z&     = Fwfs(pnggr&z&,nptr&z&)
delwf&z&     = ( (wfuelz / (thet2n * delta2 )) -  wfsr2&z& )

! ----------------  Calculate remainder of gas generator model
!             variables

t4r2&z&   = Ft4(pnggr&z&,nptr&z&,delwf&z&)
w4r2&z&   = Fw4(pnggr&z&,delwf&z&)
t4p&z&    = (t4r2&z& * thta2v)
w4&z&     = w4r2&z& * ( delta2 / sqrth2)
tut4h&z& = 0.206785 * ( w4&z& ** 0.8 ) / ( t4p&z& ** 0.4 )
t4pl&z&   = REALPL(1/tut4h&z&,t4p&z&,t4pl&z&i)
t4u&z&    = ( t4p&z& - t4pl&z& ) * tut4h&z& * 49.979957
dt4hs&z& = - ( t4u&z& / w4&z& )
t4&z&     = (dt4hs&z& + t4p&z&)
q4r2&z&   = Fq4( pnggr&z&,nptr&z&,delwf&z& )
q4&z&     = ( q4r2&z& * delta2 )
dq4s&z&   = (( dt4hs&z& / t4p&z& ) * q4&z& )
dqhr2&z& = Fdqh( pnggr&z&,delwf&z& )
qh&z&     = (( dqhr2&z& * delta2 ) + dq4s&z& )
nggz    = INTEG( qh&z& * ( ki / igg&z& ) , nggzi )
pngg&z&   = ( nggz * kpngg&z& )
pnggr&z& = pngg&z& / sqrth2
ps3r2&z& = Fps3(pnggr&z&,nptr&z&,delwf&z&)
ps3z    = ps3r2&z& * delta2
```

```
! ---------------- POWER TURBINE SECTION -------------------------

t51r2&z& = Ft51(pnggr&z&,nptr&z&,delwf&z&)
w54r2&z& = Fw54(pnggr&z&,delwf&z&)
t51p&z& = t51r2&z& * thta2v
w54&z& = w54r2&z& * ( delta2 / sqrth2)
tut51h&z& = 0.06875 * ( w54&z& ** 0.8 ) / ( t51p&z& ** 0.4 )
t51pl&z& = REALPL(1/tut51h&z&,t51p&z&,t51pl&z&i)
t51u&z& = ( t51p&z& - t51pl&z& ) * tut51h&z& * 116.0073
dt51hs&z& = - ( t51u&z& / w54&z& )
t51&z& = (dt51hs&z& + t51p&z&)
t54&z& = t51&z& - 459.7 - Tdt54&z& (pnggr&z&, nptr&z&)
t51q&z& = (t51&z& / t51p&z&)
p54r2&z& = Fp54(pnggr&z&,nptr&z&,delwf&z&)
p54z = p54r2&z& * delta2 * sqrt ( t51q&z& )
dqptr&z& = Fdqp(pnggr&z&,nptr&z&,delwf&z&,0.0,Farg0)
qez = t51q&z& * dqptr&z& * delta2

nptr&z& = nptz / sqrth2

! ---------------- Alarm and simulation shutdown section ----------

PROCEDURAL ( kalarm&z&, kshtdn&z& = t54&z&, nggz, nptz, ticz )
!
  IF ((t54&z& .GT. 1500.0) .AND. (.NOT. lt54&z&a)) THEN
      lt54&z&a = .TRUE.
      kalarm&z& = kalarm&z& + 1
      PRINT L01&z
  L01&z&..FORMAT(/,'  ===> ALARM Condition: t54&z& .GT. 1500 <==='，/)
  ELSE IF ((t54&z& .LT. 1500.0) .AND. lt54&z&a) THEN
      lt54&z&a = .FALSE.
      kalarm&z& = kalarm&z& - 1
  ELSE
      CONTINUE
  ENDIF
!
  IF (t54&z& .GT. 1530.0) THEN
      kshtdn&z&= kshtdn&z& + 1
      PRINT L02&z
  L02&z&..FORMAT(/,'  ===> SHUTDOWN Condition: t54&z& .GT. 1530 <===',/)
  ENDIF
!
  IF ((nggz .GT. 9700.0) .AND. (.NOT. lngg&z&a)) THEN
      kalarm&z& = kalarm&z& + 2
      PRINT L03&z
  L03&z&..FORMAT(/,'  ===> ALARM Condition: nggz .GT. 9700 <===',/)
  ELSE IF ((nggz .LT. 9700.0) .AND. lngg&z&a) THEN
      lngg&z&a = .FALSE.
      kalarm&z& = kalarm&z& - 2
  ELSE
      CONTINUE
  ENDIF
!
  IF (nggz .GT. 10122.0) THEN
```

```
     kshtdn&z& = kshtdn&z& + 2
     PRINT L04&z
  L04&z&..FORMAT(/,'  ===> SHUTDOWN Condition: nggz .GT. 10122 <===',/)
  ENDIF
!
  IF (nptz .GT. 3960.0) THEN
     kshtdn&z& = kshtdn&z& + 4
     PRINT L05&z
  L05&z&..FORMAT(/,'  ===> SHUTDOWN Condition: nptz .GT. 3960 <===',/)
  ENDIF
!
  IF ((nptz .LT. 100.0) .AND. (ticz .GT. 30.0)) THEN
     kshtdn&z& = kshtdn&z& + 8
     PRINT L06&z
  L06&z&..FORMAT(/,'  ===> SHUTDOWN Condition: nptz .LT. 100 <===',/)
  ENDIF
!
END

! ----------------  See if any of the data lookup tables were overrun

PROCEDURAL ( ktbl&z& = pnggr&z&,nptr&z&,p54q&z&,nptq&z&,nggz,t2 )
  ktbl&z& = 0
!
  IF ((pnggr&z& .LT. 46.81) .OP. (pnggr&z& .GT. 99.73)) THEN
     ktbl&z& = ktbl&z& + 1
     PRINT Lt1&z, pnggr&z
  Lt1&z&..FORMAT(/,'  ===> TABLE OVERRUN : 46.81 < pnggr&z& < 99.73', &
       ' <===',/,'          ( pnggr&z& = ',F6.2,' )',/)
  ENDIF
!
  IF ((nptr&z&  .LT.  600.0) .OR. (nptr&z&  .GT.  4000.0)) THEN
     ktbl&z& = ktbl&z& + 2
     PRINT Lt2&z, nptr&z
  Lt2&z&..FORMAT(/,'  ===> TABLE OVERRUN : 600 < nptr&z& < 4000', &
       ' <===',/,'          ( nptr&z& = ',F7.1,' )',/)
  ENDIF
!
  IF ((p54q&z&  .LT.   1.00) .OR. (p54q&z&  .GT.    4.60)) THEN
     ktbl&z& = ktbl&z& + 4
     PRINT Lt3&z, p54q&z
  Lt3&z&..FORMAT(/,'  ===> TABLE OVERRUN : 1.00 < p54q&z& < 4.60', &
       ' <===',/,'          ( p54q&z& = ',F4.2,' )',/)
  ENDIF
!
  IF ((nptq&z&  .LT. 21.933) .OR. (nptq&z&  .GT. 175.467)) THEN
     ktbl&z& = ktbl&z& + 8
     PRINT Lt4&z, nptq&z
  Lt4&z&..FORMAT(/,'  ===> TABLE OVERRUN : 21.93 < nptq&z& < 175.47', &
       ' <===',/,'          ( nptq&z& = ',F7.2,' )',/)
  ENDIF
!
  IF ((nggz   .LT. 4000.0) .OR. (nggz   .GT. 10000.0)) THEN
     ktbl&z& = ktbl&z& + 32
     PRINT Lt5&z, nggz
```

```
  Lt5&z&..FORMAT(/,'  ===> TABLE OVERRUN : 4000 < nggz < 10000',  &
      ' <==='',/,'          ( pnggr&z& = ',F7.1,' )',/)
  ENDIF
!
  IF ((t2    .LT.  430.0) .OR. (t2    .GT.   595.0)) THEN
      ktbl&z& = ktbl&z& + 64
      PRINT Lt6&z, t2
  Lt6&z&..FORMAT(/,'  ===> TABLE OVERRUN : 430 < t2 < 595',  &
      ' <==='',/,'          ( t2 = ',F6.1,' )',/)
  ENDIF
!
END

!  This simulation termination criteria should be enabled when the
!  final outer loop controls and generator and motor models are
!  installed.

    TERMT (kshtdn&z& .gt. 0,' ===> TURBINE SHUTDOWN OCCURRED ')
    TERMT (ktbl&z& .gt. 0,' ===> TABLE OVERRUN OCCURRED ')

MACRO END

!  >>>>>>>  End Gas Generator and Power Turbine Model MACRO <<<<<<<
!  -----------------------------------------------------------------
```

A.10 Gas Turbine Governor

```
!  ================================================================
!  >>>>>> Begin Power Turbine Shaft Speed Control Model MACRO <<<<<
!  ================================================================
!   file name:  LM25crpm4.mac   clp 22-nov-91
!
!   This macro is a slight modification of "LM25crpm2.mac"
!   to permit testing of the reduced-order models of the
!       electrical components.
!
!   This program generates a throttle input command (ticmdz)
!   to control power turbine shaft speed to a reference input
!   which is equated to the base shaft RPM (for the LM2500 the
!   base speed is fixed at 3600 RPM).  The controller sums two
!   inputs (ticn and tics) which are generated by a P/I
!   controller and a horsepower demand circuit, respectively.
!   The power demand circuit accepts a desired per unit steady
!   state power demand and determines the equivalent steady
!   state power lever angle (tics).  (NOTE:  the P/I controller
!   has been "tuned" to a reference speed of 3600 RPM and the
!   table "Talpha&z&" has been developed for that speed.)
!
!   The P/I controller generates an error signal,
!
!       nerr = nptref - npt
!
!
!  ----------------------------------------------------------------
!
!  MODELING CONVENTIONS:
```

```
!  ------------------
!
!  (1)  Use CAPS for ACSL statements, ACSL variables, etc.
!
!  (2)  Use lower case for all model variables.
!
!  (3)  Begin Table names, Function names and related control
!   variables with a capital letter.
!
!  ---------------------------------------------------------------
!
!  CHANGE RECORD:
!  ------------
!
!  Version   Date    Engr    Description
!  -------  -------  ----  ---------------------------------------
!     0     22nov91  clp   Model developed and installed.
!
!     1     13may92   ow   deleted "CONSTANT lpwrdz = .FALSE."
!
!     2     19jun92   ow   deleted variables hpgen, lpwrdz, and hpgeni
!
!     3     02nov92  tjm   declared lhold&z&PI as LOGICAL to fix PC
!                          compiler problem.
! ----------------------------------------------------------------


   MACRO  LM25crpm4(z,nptzb,nptzord,nptzordi,nptzi,nptz,hpzb, &
                    hpgen,hpgeni,hpzord,hpzordi,lpwr, &
                    ticzul,ticzll,ticmdz,ticmdzi)

!   inputs:          z = concatenation variable
!                nptzb = power turbine shaft speed base RPM
!              nptzord = ordered power turbine shaft RPM
!             nptzord1 = ordered power turbine shaft RPM IC
!                nptzi = power turbine shaft speed IC
!                 nptz = power turbine shaft speed RPM
!                 hpzb = power turbine shaft base horsepower
!                hpgen = generator horsepower
!               hpgeni = generator horsepower IC
!               hpzord = ordered turbine horsepower
!              hpzordi = per unit turb horsepower desired IC
!                 lpwr = true for power demand mode
!
!   outputs:  ticmdz = throttle input command
!            ticmdzi = throttle input command IC

! ---------------  Define the table for alpha= f(percent qpt).  This
!           table was originally developed using LM25test.csl
!           with alphaqpt.rtc to obtain IC values of alpha for
!           kqload values corresponding to the percent base
!           load torque of a 25000 SHP power turbine operating
!           a 3600 RPM.  Then, when the controller was added
!           to LM25test.csl, the data was refined by setting
!           khpsstl to the per unit equivalent of percent HP
```

```
!           and using the command sequence:
!
!           SET tstp=0
!           START
!           ANALYZ/TRIM
!           D khpsstl, alphatl
!
!          to determine the trimmed value of alphatl.  An
!          additional point was added for khpsstl=1.05 pu.
!

TABLE Talpha&z&,1,16/                                           &
       -100.0, 00.0, 05.0, 10.0, 20.0, 30.0, 40.0, 50.0,        &
         60.0, 70.0, 80.0, 90.0, 100.0, 105.0, 110.0, 999.9,    &
       13.000, 13.000, 49.4295, 54.6614, 61.0988, 66.6192,      &
       71.5426, 75.7921, 80.0053, 84.1948, 88.9893, 94.0248,    &
       98.9640, 102.5660, 108.0, 108.0 /

LOGICAL lhold&z&PI

! +++++++ Begin INITIAL Section ++++++++++++++++++++++++++++++++++

INITIAL

lhold&z&PI = .false.
! ---------------- Power turbine shaft speed reference setpoint


npt&z&ri = nptzordi

! ---------------- Calculate speed controller throttle input
!           command IC

nerr&z&i = npt&z&ri - nptzi
pcntrl&z&i = kcl&z& * nerr&z&i
icntrl&z&i = nerr&z&i
ticn&z&i = pcntrl&z&i + icntrl&z&i

pwrd&z&i = 100 * (hpzordi / hpzb)
tics&z&i = Talpha&z&(pwrd&z&i)

ticmdzi = (ticn&z&i + tics&z&i)

END !  ++++++++++++ of INITIAL

! +++++++ Begin DERIVATIVE Section +++++++++++++++++++++++++++++++

! ---------------- Shaft speed control constants

CONSTANT  kcl&z& = 0.5, tcl&z& = 3.0

! ---------------- P/I integrator bound

CONSTANT  iclim&z& = 70.0      ! limit integrator to avoid windup
```

```
! ---------------- Shaft speed controller ( generates throttle input
!           command -- ticmdz = ticn + tics). A simple P/I
!           controller generates the ticn term given a
!           reference speed, the actual speed and a calculated
!           delta RPM proportional to horsepower demand. The
!           tics term is based on a per unit desired horsepower
!           input command. Since constant speed is assumed,
!           the per unit horsepower is also the per unit torque.

hpt&z&ord = RSW(lpwr,hpzord,hpgen)    ! ordered turbine hp
npt&z&r = nptzord
hp&z&d = BOUND(0.0, hpzb, hpt&z&ord)  ! -- limit demand to rated HP

nerr&z& = (npt&z&r - nptz)                 ! speed error
pcntrl&z& = (kcl&z& * nerr&z&)             ! proportional control
icntrl&z& = LIMINT((kcl&z&/tcl&z&)*nerr&z&*kholdPI&z&, nerr&z&i, &
                    -iclim&z&, iclim&z&)   ! integral control

ticn&z& = pcntrl&z& + icntrl&z        ! -- ticn

pwrd&z& = 100 * (hpt&z&ord / hpzb)    ! -- percent power demand
tics&z& = Talpha&z&(pwrd&z&)          ! -- tics

PROCEDURAL (ticmdz, kholdPI&z& = ticzul,ticzll)
   ticmdz = (ticn&z& + tics&z&)
   IF((nerr&z& .GT. 0.0) .AND. (ticmdz .GT. (ticzul+1.0)))THEN
         lhold&z&PI = .TRUE.
   ELSE IF ((nerr&z& .LT. 0.0) .AND. (ticmdz .LT. (ticzll-1.0)))THEN
         lhold&z&PI = .TRUE.
   ELSE
         lhold&z&PI = .FALSE.
   ENDIF
   kholdPI&z& = RSW(lhold&z&PI, 0.0, 1.0)
END ! of procedural

MACRO END

!>>>>>>>> End Power Turbine Shaft Speed Control Model MACRO <<<<<<<<
!-------------------------------------------------------------------
```

A.11 Gas Turbine Mechanical Interface

```
!  ================================================================
!  >>>>>>  Begin Source/Load Interface Dynamics Model MACRO  <<<<<<
!  ================================================================
!   file name:  tgid2.mac   clp 13-may-91
!
!   This program models the mechanical dynamics interface
!   between a prime mover (such as a gas turbine) and its load
!   (such as a generator) as a simple reduction gear.  The
!   model includes a reduction gear and all variables are
!   referred to the DRIVE (source) shaft.  It does not include
!   shaft torsional dynamics.  One SIGNIFICANT VARIATION is
!   that it computes drive shaft acceleration as d(RPM)/dt
!   rather than d(RAD/SEC)/dt.  A gear torque loss term is
!   included in the model.  The gear loss coefficient, pctid,
```

```
!   has been set to a nominal value of 0.01 which can be
!   changed at run time.
!
!   The model is a modification of tgid1.mac which has been
!       developed for all variables referred to the load shaft.
!   As in the case of tgid1.mac, the inertia inputs must be
!   specified in the WR^2 (LBm-FT^2) form.
!
!    Needs following parameters:
!
!            rpmrad, gcons
!
!    from:  /home/ra4/patterson/acsl/constants.mod
!
!  -----------------------------------------------------------------
!
!  MODELING CONVENTIONS:
!  --------------------
!
!  (1)  Use CAPS for ACSL statements, ACSL variables, etc.
!
!  (2)  Use lower case for all model variables.
!
!  (3)  Begin Table names, Function names and related control
!   variables with a capital letter.
!
!  -----------------------------------------------------------------
!
!  CHANGE RECORD:
!  -------------
!
! Version   Date    Engr    Description
! -------  -------  ----  ---------------------------------------
!    0     15may91  clp   Model developed and installed.
!
!    1     06apr93  tjm   Changed pctid1 to pctid&z& to allow
!                         using more than one unit.
!
! -----------------------------------------------------------------

MACRO  tgid2(z,qsrc,jjsrc,nsrcb,qsrcb,qloadi,qload,jjload,nloadb, &
             nloadi,dnsrc,nsrc,nsrci,qsrci,dnload,nload)

!   inputs:        z = concatenation variable (1, 2, g1, etc)
!               qsrc = input (source) shaft drive torque [LB-FT]
!              jjsrc = input shaft inertia [LB-FT^2]
!              nsrcb = input shaft base speed [RPM]
!              qsrcb = input shaft base torque [LB-FT]
!             qloadi = output (load) shaft initial torque [LB-FT]
!              qload = output (load) shaft torque [LB-FT]
!             jjload = output shaft inertia [LB-FT^2]
!             nloadb = output shaft base speed [RPM]
!             nloadi = output  shaft initial speed [RPM]
!
!   outputs:   dnsrc = input shaft base accel [RPM/SEC]
```

```
!           nsrc = input shaft base speed [RPM]
!          nsrci = input  shaft initial speed [RPM]
!          qsrci = input shaft initial torque [LB-FT]
!         dnload = output (load) shaft accel [RPM/SEC]
!          nload = output (load) shaft speed [RPM]

CONSTANT    pctid&z& = 0.01    ! -- percent loss torque factor

! +++++++ Begin INITIAL Section ++++++++++++++++++++++++++++++++++

INITIAL

! ---------------- Calculate gear speed ratio

id&z&gr = nsrcb / nloadb

! ---------------- Calculate total inertia referred to load shaft

iitid&z& = (jjsrc / gcons) + (jjload / gcons) / id&z&gr**2

! ---------------- Calc initial source shaft speed

nsrci = nloadi * id&z&gr

! ---------------- Calc torque loss constant and initial torque loss

cqlid&z& = (pctid&z& * qsrcb) / (nsrcb*nsrcb)
qlid&z&i = cqlid&z& * nsrci * ABS(nsrci)

! ---------------- Calc initial source shaft torque

qsrci = (qloadi + qlid&z&i) / id&z&gr

END !  ++++++++++++ of INITIAL

! +++++++ Begin DERIVATIVE Section ++++++++++++++++++++++++++++++++++

! ---------------- Calc LOAD shaft speed (accel) in units of
!          RPM (RPM/SEC)

qlid&z& = cqlid&z& * nsrc * ABS(nsrc)

dnsrc = (rpmrad * (qsrc - (qload/id&z&gr) - qlid&z&) / iitid&z&)
nsrc = INTEG (dnsrc, nsrci)

! ---------------- Calc SOURCE shaft speed (accel) in units of
!          RPM (RPM/SEC)

dnload = dnsrc / id&z&gr
nload = nsrc / id&z&gr

MACRO END

!  >>>>>>>>  End Source/Load Interface Dynamics Model MACRO  <<<<<<<<<
!  -------------------------------------------------------------------
```

A.12 Mechanical Load

```
!=====================================================================
!
!                         Mechanical Load Model
!
!                  Copyright 1992 by Timothy J. McCoy
!
!=====================================================================
!
!   Macro:      load.mac
!
!   Function:   Models a mechanical load applied to a motor.  Allows
!               various types of loads to be simulated through the use
!               of a second order polynomial.
!
!                           Concatenation
!   z           =   machine identifier
!
!                           Inputs
!   wm          =   machine speed [per unit]
!
!                           Outputs
!   tm          =   mechanical load torque[per unit]
!
!                           Constants
!   a&z&        =   quadratic polynomial constant [ ]
!   b&z&        =   linear polynomial constant [ ]
!   c&z&        =   constant term of polynomial [ ]
!
!                           State variables
!                   NONE
!
!                           Initial Conditions
!                   NONE
!
!=====================================================================

MACRO load (z,wm,tm)

    CONSTANT a&z&  =   0.0
    CONSTANT b&z&  =   0.0
    CONSTANT c&z&  =   0.0

INITIAL

END !--- of initial section

!---beginning of derivative section

    tm  =   a&z&*wm**2 + b&z&*wm + c&z&

!---end of derivative section
MACRO END
```

A.13 Ship's Service Load

```
!------------------------------------------------------------------
!
!                          Ship's Service Load
!
!                   Copyright 1993 by Timothy J. McCoy
!
!==================================================================
!                         Record of Changes
!
! No.  Date    By      Summary
! ---  ------  ---     ----------------------------------------
!  0   3-27-93 tjm     Model written.
!==================================================================
!   macro: shipserv.mac
!   function:  models a constant power load
!                              CONCATENATION
!   z       = motor identifier
!
!                              INPUTS
!   vd      = D-axis terminal voltage [per unit]
!   vq      = Q-axis terminal voltage [per unit]
!
!                              OUTPUTS
!   id      = D-axis terminal current [per unit]
!   iq      = Q-axis terminal current [per unit]
!
!                              CONSTANTS
!   p&z&    = Real power load [per unit]
!   q&z&    = Reactive power load [per unit]
!
!                              INTERNAL
!             NONE
!==================================================================

MACRO shipserv (id,iq , vd,vq,z)
!==================================================================
!                 Begin Derivative Section
!==================================================================
!---parameters
CONSTANT p&z&       = 0.0
CONSTANT q&z&       = 0.0

PROCEDURAL(id,iq,q&z&,p&z&)
    vt&z&2  = vd*vd + vq*vq
    id      = (vd*p&z& + vq*q&z&)/vt&z&2
    iq      = (vq*p&z& - vd*q&z&)/vt&z&2
END !---of procedural

MACRO END !---of shipserv
```

A.14 Base Conversions

```
!------------------------------------------------------------------
```

```
!
!                         BASE CONVERSION MACRO
!
!                   Copyright 1993 by Timothy J. McCoy
!
!=====================================================================
!                            Record of Changes
!
! No.  Date    By     Summary
! ---  ------  ---    ----------------------------------------------
!  0   4-08-93 tjm    Model written.
!=====================================================================
!
!   macro:     baseconv
!   function:  calculates conversion factors for converting
!              quantities from one base to another base.
!
!                         CONCATENATION
!              NONE
!
!                         INPUTS
!  basev1  =   base voltage converted from
!  basev2  =   base voltage converted to
!  basekw1 =   base power converted from
!  basekw2 =   base power converted to
!
!                         OUTPUTS
!  kv12    =   voltage conversion factor
!  kkw12   =   power conversion factor
!  ki12    =   current conversion factor
!  kz12    =   impedance conversion factor
!
!                         CONSTANTS
!              NONE
!
!=====================================================================
MACRO baseconv(kv12,kkw12,ki12,kz12 , basev1,basev2,basekw1,basekw2)

kv12    = basev1/basev2
kkw12   = basekw1/basekw2
ki12    = kkw12/kv12
kz12    = kv12**2/kkw12

MACRO END ! of baseconv
```

A.15 Miscellaneous Constants

```
!--------------------------------------------------------------------
!
!             PHYSICAL CONSTANTS INCLUSION FILE
!
!             Copyright 1993 by Timothy J. McCoy
!
!--------------------------------------------------------------------
!                  CONSTANTS
```

```
!
!    NAME              VALUE                            USED BY
!    --------          -------------------------        ----------------------
!    krt3              = SQRT(3)         = 1.7320508    vreg2.mac, freqchg2.mac
!    krt302            = SQRT(3)/2       = 0.8660254    vreg2.mac
!    kpio2             = PI/2            = 1.570796     conmtr.mac
!    k3rt3opi          = 3*SQRT(3)/PI    = 1.6539866    freqchg2.mac
!    k2rt3opi          = 2*SQRT(3)/PI    = 1.1026577    freqchg2.mac, conmtr,mac
!    k2ort3            = 2/SQRT(3)       = 1.1547005    freqchg2.mac
!    kpi               = PI              = 3.1415927    conmtr.mac
!----------------------------------------------------------------------
PARAMETER (krt3o2   = 0.8660254)
PARAMETER (kpio2    = 1.570796)
PARAMETER (k3rt3opi = 1.65398669)
PARAMETER (krt3     = 1.73205081)
PARAMETER (k2rt3opi = 1.10265779)
PARAMETER (k2ort3   = 1.154700538)
PARAMETER (kpi      = 3.1415927)
!---END of 'constant.inc'
```

A.16 Circuit Breaker

```
!---------------------------------------------------------------------
!
!                        Circuit Breaker Model
!
!                 Copyright 1993 by Timothy J. McCoy
!
!=====================================================================
!                          Record of Changes
!
!  No.  Date    By     Summary
!  ---  ------  ---    ----------------------------------------------
!   0   4-21-93 tjm    Model written.
!=====================================================================
!   macro: cb.mac
!   function:  models a lossless switch for disconnecting generators
!              from the main bus (works for components which input
!              currents and output voltages).
!
!                          CONCATENATION
!
!                             INPUTS
!   lcb        = logical variable to indicate closed (.TRUE.)
!                or open (.FALSE.)
!   vdbus      = D-axis bus voltage [per unit]
!   vqbus      = Q-axis bus voltage [per unit]
!   vdgen      = D-axis generator terminal voltage [per unit]
!   vqgen      = Q-axis generator terminal voltage [per unit]
!   id         = D-axis generator terminal current [per unit]
!   iq         = Q-axis generator terminal current [per unit]
!
!                             OUTPUTS
!   vdcb       = D-axis circuit breaker voltage [per unit]
!   vqcb       = Q-axis circuit breaker voltage [per unit]
!   idcb       = D-axis circuit breaker current [per unit]
```

```
!   iqcb      = Q-axis circuit breaker current [per unit]
!
!                              CONSTANTS
!
!                              INTERNAL
!
!=====================================================================
MACRO cb (vdcb,vqcb,idcb,iqcb , lcb,vdbus,vqbus,vdgen,vqgen,id,iq)
!=====================================================================
!                 Begin Derivative Section
!=====================================================================
IF(lcb)THEN
    vdcb     = vdbus
    vqcb     = vqbus
    idcb     = id
    iqcb     = iq
ELSE
    vdcb     = vdgen
    vqcb     = vqgen
    idcb     = 0.0
    iqcb     = 0.0
ENDIF
MACRO END !---of cb
```

A.17 Inverse Park's Transform

```
!---------------------------------------------------------------------
!
!               INVERSE PARK'S TRANSFORMATION DQ-->ABC VARIABLES

!
!               Copyright 1992 by Timothy J. McCoy
!
!---------------------------------------------------------------------
!
!=====================================================================
!                        Record of Changes
!
!   No. Date     By     Summary
!   --- ------   ---    ------------------------------------------
!   0.  12-1-92  tjm    Model written.
!   1.  12-3-92  tjm    Removed Definition of twopi3, it is defined
!                       in 'constants.inc'.
!   2.  12-6-92  tjm    Changed to unitary form of transformation.
!   3.  3-15-93  tjm    Changed back to Prof. Kirtley's transformation
!=====================================================================
!
!    macro:     ipark
!    function:  Performs an inverse D-Q transformation on its inputs.

!
!                              CONCATENATION
!                   none

!                              INPUTS
```

```
!       fq      = Q-axis variable [per unit]
!       fd      = D-axis variable [per unit]
!       theta   = the integral of the speed of rotation of the D-Q
!                 reference frame.
!
!                             OUTPUTS
!       fa      = A-phase variable [per unit]

!       fb      = B-phase variable [per unit]
!       fc      = C-phase variable [per unit]
!
!                            CONSTANTS
!       k2pio3  = 2*pi/3 = 2.094395
!       krt2o3  = sqrt(2/3) = 0.81649658
!
!                  INTERNAL (STATE OR STATE RELATED)
!               none
!
!                  INTERNAL (NOT STATE RELATED)
!               none
!====================================================================
CONSTANT k2pio3 = 2.094395

MACRO ipark (fa,fb,fc,fq,fd,theta)

!====================================================================
!               Begin Derivative Section
!====================================================================

fa = (fd*cos(theta)          - fq*sin(theta))
fb = (fd*cos(theta - k2pio3) - fq*sin(theta - k2pio3))
fc = (fd*cos(theta + k2pio3) - fq*sin(theta + k2pio3))

!====================================================================
!               End of Derivative Section
!====================================================================

MACRO END ! of ipark
```

A.18 Park's Transform

```
!--------------------------------------------------------------------
!
!              PARK'S TRANSFORMATION ABC-->DQ VARIABLES
!
!              Copyright 1992 by Timothy J. McCoy
!
!--------------------------------------------------------------------
!
!====================================================================
!                          Record of Changes
!
!  No. Date     By     Summary
!  --- ------   ---    -------------------------------------------
!  0.  12-1-92  tjm    Model written.
```

```
!   1.  12-3-92  tjm    Removed Definition of twopi3, it is defined
!                       in 'constants.inc'.
!   2.  12-6-92  tjm    Changed to unitary form of transformation.
!   3.  3-15-93  tjm    Changed back to Prof. Kirtley's transformation
!=====================================================================
!
!    macro:     park
!    function:  Performs a D-Q transformation on its inputs.

!
!                             CONCATENATION
!       z       = synchronous machine identifier
!
!                             INPUTS
!       fa      = A-phase variable [per unit]

!       fb      = B-phase variable [per unit]
!       fc      = C-phase variable [per unit]
!       theta   = the integral of the speed of rotation of the D-Q
!                 reference frame.
!
!                             OUTPUTS
!       fq      = Q-axis variable [per unit]
!       fd      = D-axis variable [per unit]
!
!                             CONSTANTS
!       k2pio3  = 2*pi/3 = 2.094395
!       krt2o3  = sqrt(2/3) = 0.81649658
!
!                  INTERNAL (STATE OR STATE RELATED)
!               none
!
!                  INTERNAL (NOT STATE RELATED)
!               none
!=====================================================================
CONSTANT k2o3   = 0.66666667


MACRO park (fq,fd , fa,fb,fc,theta)

!=====================================================================
!               Begin Derivative Section
!=====================================================================

fd = k2o3*(fa*cos(theta)+fb*cos(theta-k2pio3)+ &
     fc*cos(theta + k2pio3))
fq = -k2o3*(fa*sin(theta)+fb*sin(theta-k2pio3)+ &
     fc*sin(theta + k2pio3))

!=====================================================================
!               End of Derivative Section
!=====================================================================

MACRO END ! of park
```

A.19 Ship Dynamics

```
!---------------------------------------------------------------------
!
!                         SHIP DYNAMICS MODEL
!
!              Copyright 1993 by Timothy J. McCoy
!
!             The macros used herein were written by
!              C.L. Patterson, NSWC, Annapolis, MD

!=====================================================================
!                         Record of Changes
!
!  No.  Date     By      Summary
!  ---  ------  ---      ------------------------------------------
!   0   3-29-93 tjm      Model written.
!=====================================================================
!
!   macro:     ship
!   function:  Models the hydrodynamic propeller load placed on

!              a propulsion motor
!
!                          INPUTS
!   wrn1      = Starboard propeller shaft speed [per unit]
!   wrn2      = Port propeller shaft speed [per unit]
!
!                          OUTPUTS
!   tml       = mechanical torque load on starboard motor [per unit]
!   tml       = mechanical torque load on port motor [per unit]
!
!                          CONSTANTS
!   kbaserpm = base propeller shaft rpm
!   kqbase   = base shaft torque [LB-FT]
!   jjps     = propeller/shaft inertia in [LB/FT^2]
!
!                          INTERNAL
!------------------Inputs to 'ship1a.mac'
!     np1rpm = propeller shaft speed [RPM]
!     np2rpm = propeller shaft speed [RPM]
!      wesea = seaway velocity factor [per unit]
!     lheadr = logical ( = .T. to begin headreach calc)
!
!------------------Inputs to 'seaway.mac'
!      vslpu = ship velocity normalized [per unit]
!
!------------------Outputs from 'ship1a.mac'
!       jjps = total prop/shaft inertia [LB-FT^2]
!    np1rpmi = initial shaft speed [RPM]
!       qp1i = initial shaft torque [LB-FT]
!        qp1 = shaft torque [LB-FT]
!      qp1fi = initial shaft frictional loss torque [LB-FT]
!       qp1f = shaft frictional loss torque [LB-FT]
!    np2rpmi = initial shaft speed [RPM]
```

```
!        qp2i = initial shaft torque [LB-FT]
!         qp2 = shaft torque [LB-FT]
!       qp2fi = initial shaft frictional loss torque [LB-FT]
!        qp2f = shaft frictional loss torque [LB-FT]
!       vslpu = per unit ship speed
!     lcalchr = logical ( = .T. to permit headreach calc)
!     lvship0 = logical ( SCHEDULE flag = .T. when vs=0.0)
!     headrpu = headreach on vsl per unit base
!     t0vship = time at which headreach calc starts
!     tvship0 = time req'd to stop ship from start of headr
!     xvship0 = headreach distance on vsl per unit base
!      qpsbaf = propeller shaft breakaway friction [LB-FT]
!      nprpmb = propeller shaft speed base [RPM]
!      qpbase = propeller shaft torque base [LB-FT]
!
!------------------Outputs from 'seaway.mac'
!       wesea = seaway velocity factor [per unit]
!        lsea = logical flag set .TRUE. to invoke seaway
!    ldoppler = logical flag set .TRUE. to invoke an
!                       effective doppler seaway frequency
!======================================================================
!                            MACROS
!======================================================================
INCLUDE 'c:\acsl\ship\macros\ship1a.mac'
INCLUDE 'c:\acsl\ship\macros\seaway1.mac'
INCLUDE 'c:\acsl\ship\macros\constant.inc'
!======================================================================

MACRO ship (tm1,tm2 , wrn1,wrn2,kbaserpm)

!======================================================================
!                 Begin Derivative Section
!======================================================================


!---convert shaft speed to rpm
np1rpm = wrn1*kbaserpm
np2rpm = wrn2*kbaserpm

!---convert shaft torque to per unit for output
tm1    = -qp1/qpbase
tm2    = -qp2/qpbase

!---Invoke ship dynamics macro
ship1a(1,np1rpm,np2rpm,wesea , lheadr,jjps,np1rpmi,qp1i,qp1,qp1fi, &
       qp1f,np2rmpi,qp2i,qp2,qp2fi,qp2f,vslpu,lcalchr,lvship0, &
       headrpu,t0vship,tvship0,xvship0,qpsbaf,nprpmb,qpbase)

!---Invoke seaway macro
seaway(1,lsea,ldoplr,vslpu,wesea)

!======================================================================
!                 End of Derivative Section
!======================================================================
MACRO END ! of ship
```

```
! ------------------------------------------------------------------
! -------------------- ACSL MODEL CONSTANTS
!
!   file name:  constants.mod
!
!   created:    13-JAN-86   CLP (VAX ACSL_CONS.MOD)
!
!   revision:   26-feb-91   clp modified for SUN,
!                           mod pi, add twopi
!
!           19-apr-91   clp add elec pwr sys
!                       parameters: forfve,
!                       ninety, twopio3,
!                       omega60b
!
!           18-oct-91   clp add inertia constant
!                       factors khh1 and khh2
!
! ==================================================================

!    >>>>> ESTABLISH GENERAL CONSTANTS <<<<<

! ------------- Miscellaneous Model Constants ---------------------

PARAMETER (pi = 3.1415926536)       ! [non-dimensional]
PARAMETER (twopi = 6.28318530718)   ! [non-dimensional]
PARAMETER (sqrt2 = 1.41421)     ! [non-dimensional]
PARAMETER (sqrt3 = 1.73205)     ! [non-dimensional]

PARAMETER (rho = 1.9905)        ! [(lb-sec^2)/ft^4]
PARAMETER (gcons = 32.174)      ! [ft/sec^2]

PARAMETER (ftlbhp = 550.)       ! [ft-lb/sec)/hp]
PARAMETER (watthp = 745.7)      ! [watts/hp]
PARAMETER (kwathp = .7457)      ! [kilowatts/hp]

! ------------- RPM = RAD/SEC * [ 60. / (2. * PI) ] ---------------

PARAMETER (rpmrad = 9.549296)   ! [rpm/(rad/sec)]

! ------------- FT/SEC = KNOTS * [ 6076.1 / 3600. ] ---------------

PARAMETER (fpskt = 1.687806)    ! [(ft/sec)/knot]

! ------------- Inertia constant factors for use in calculating HH
!       given the inertia in JJ (WR^2 [lbm-ft^2]) form, the
!       shaft speed in N [rpm], and either KVA or Q [lbf-ft].
!
!   ------  for the form:  HH = khh1 * ( JJ * N^2 / KVA)
!
!        khh1 = (1/2)*[(1/2.204)*(1/3.2808)^2]*(2*pi/60)^2

PARAMETER (khh1 = 2.3094e-7)
```

```
!   ------  for the form:  HH = khh2 * ( JJ * N / Q)
!
!        khh2 = khh1 * (kwathp / ftlbhp)

PARAMETER (khh2 = 2.99165e-3)

! ------------- Useful constants and parameters for ---------------
!       electrical power systems simulations
!       involving solid state, 6-pulse rectifier
!       cicuits.  Based on data provided by
!       Purdue for the Pulse Power charger model.
!          (added by ===> clp    19,25-apr-91)

PARAMETER (eps = 1.0e-6)          ! a small number

PARAMETER (omega60b = 377.0)      ! [ base radian freq for 60 Hz ]

PARAMETER (forfve = 0.78539816) ! [ (pi/4) equiv 45 deg ]
PARAMETER (ninety = 1.57079633) ! [ (pi/2) equiv 90 deg ]
PARAMETER (twopio3 = 2.0943951) ! [ (2*pi/3) equiv 120 deg ]

PARAMETER (cfac6P = 1.10265779) !  current factor -- (2*sqrt(3))/pi
PARAMETER (vfac6P = 1.6539867)  !  voltage factor -- (3*sqrt(3))/pi
PARAMETER (zfac6P = 0.9549297)  !  impedance factor -- 3/pi


! ------------- Model function lookup flags -----------------------

INTEGER     Farg0, Farg1, Farg2, Farg3
INTEGER     Fargs0, Fargs1, Fargs2, Fargs3

CONSTANT  Farg0 = 0      !  FORWARD lookup
CONSTANT  Farg1 = 1      !  BACKWARD lookup
CONSTANT  Farg2 = 2      !   1,2, or 3 flags the
CONSTANT  Farg3 = 3      !   dependent argument
CONSTANT  Fargs0 = 0
CONSTANT  Fargs1 = 1
CONSTANT  Fargs2 = 2
CONSTANT  Fargs3 = 3

!        >>>>> END of ESTABLISH GENERAL CONSTANTS <<<<<
! -----------------------------------------------------------------

!  ==============================================================
!  >>>>>>  Begin Source/Load Interface Dynamics Model MACRO  <<<<<<
!  ==============================================================
!   file name:  mpidlf.mac  clp 7-oct-91
!
!   This program models the mechanical dynamics interface
!   between a prime mover (such as a gas turbine or motor) and its
!   load (such as a generator or propeller) as a simple reduction
!   gear.  The model includes a reduction gear and all variables
!   are referred to the output (load) shaft.  It does not include
!   shaft torsional dynamics.  One SIGNIFICANT VARIATION is that
```

```
!   it computes drive shaft acceleration as d(RPM)/dt rather than
!   d(RAD/SEC)/dt.  A gear torque loss term is included in the
!   model.  The gear loss coefficient, pctid, has been set to a
!   nominal value of 0.005 which can be changed at run time.
!
!   The model is a modification of tgid1.mac which was developed
!   for all variables referred to the load shaft.  The differences
!   are that this model also accepts load shaft friction as an
!   input and the gear ratio is given as a constant rather than
!   being calculated.  Since propeller shaft friction can be
!   significant at low shaft speed, the model checks to see if
!   shaft sticking occurs.
!
!   This model is a modified version of that developed by PDI as
!   the subroutine SHAFT.FOR in a MACRO form which employs the ACSL
!   SCHEDULE function to determine shaft sticking.  NOTE: The sign
!   of the friction torque is determined within the shaft friction
!   function (Q1Apsf.for for ship1a).
!
!   As in the case of tgid2.mac, the inertia inputs must be
!   specified in the WR^2 (LBm-FT^2) form.  For this model a
!   gearbox inertia term is included.
!
!    Needs following parameters:
!
!            rpmrad, gcons, khh2
!
!    from:  /home/ra4/patterson/acsl/constants.mod
!
!  -------------------------------------------------------------------
!
!  MODELING CONVENTIONS:
!  --------------------
!
!  (1)  Use CAPS for ACSL statements, ACSL variables, etc.
!
!  (2)  Use lower case for all model variables.
!
!  (3)  Begin Table names, Function names and related control
!   variables with a capital letter.
!
!  -------------------------------------------------------------------
!
!  CHANGE RECORD:
!  -------------
!
! Version   Date     Engr    Description
! -------  -------   ----   ------------------------------------------
!    0     07oct91   clp    Model developed and installed.
!
!    1     21-oct91  clp    Make gear ratio a constant rather than
!                           the calculation of [ nsrcb / nloadb ]
!
!    2     02jun92   jgc    pctid&z& and qlid&z& changed to pctids&z&
!                           and qlids&z& so as to not conflict with
```

```
!                           same variables in turbine model
!
!    3     08jun92  jgc   the constant cqlid&z& is changed to cqlids&z&
!                         so as to not conflict with turbine constant;
!                         also this constant is computed in INITIAL
! ---------------------------------------------------------------
MACRO  mpid1f(z,qsrc,jjsrc,nsrcb,qsrcb,qloadi,qload,qloadb,jjload, &
             nloadb,nloadi,qloadfi,qlsfgr,lstukzgr,qloadsbf,dnsrc, &
             nsrc,nsrci,qsrci,dnload,nload,delqzgr,ngrlzpu)

!   inputs:         z = concatenation variable (1, 2, g1, etc)
!                qsrc = input (source) shaft drive torque [LB-FT]
!               jjsrc = input shaft inertia [LB-FT^2]
!               nsrcb = input shaft base speed [RPM]
!               qsrcb = input shaft base torque [LB-FT]
!              qloadi = output (load) shaft initial torque [LB-FT]
!               qload = output (load) shaft torque [LB-FT]
!              qloadb = output (load) shaft torque base [LB-FT]
!              jjload = output shaft inertia [LB-FT^2]
!              nloadb = output shaft base speed [RPM]
!              nloadi = output  shaft initial speed [RPM]
!             qloadfi = load shaft initial friction torque [LB-FT]
!              qlsfgr = load shaft friction torque [LB-FT]
!            lstukzgr = logical (= .T. if shaft stuck)
!            qloadsbf = load shaft breakaway force [LB-FT]
!
!   outputs:    dnsrc = input shaft base accel [RPM/SEC]
!                nsrc = input shaft base speed [RPM]
!               nsrci = input  shaft initial speed [RPM]
!               qsrci = input shaft initial torque [LB-FT]
!              dnload = output (load) shaft accel [RPM/SEC]
!               nload = output (load) shaft speed [RPM]
!             delqzgr = load shaft accel torque difference [LB-FT]
!             ngrlzpu = load shaft speed [per unit]

CONSTANT    pctids&z& = 0.005    ! -- percent loss torque factor
CONSTANT    jjmpid&z& = 665600   ! -- gearbox WR^2 [LBM-FT^2] referred
!                     to load shaft (20700 LBF-FT-S^2)
CONSTANT    mpid&z&gr = 6.0      ! -- gear ratio (nsrc / nload) based
!                     on data provided by Code 27B (HNR)
! +++++++ Begin INITIAL Section +++++++++++++++++++++++++++++++++++
INITIAL
! ---------------- Calculate total inertia referred to load shaft
jjmpid&z&t = jjsrc * mpid&z&gr**2 + jjmpid&z& + jjload
hhmpid&z&t = khh2*jjmpid&z&t*(nsrcb/mpid&z&gr)/(qsrcb*mpid&z&gr)
iimpid&z& = jjmpid&z&t / gcons

"This is a test, this constant must be defined"
cqlids&z& = (pctids&z& * qsrcb) / (nsrcb*nsrcb)

! ---------------- Calc initial source shaft speed and torque
PROCEDURAL (nsrci,qsrci = nloadi,mpid&z&gr,pctids&z&,qsrcb,nsrcb,  &
                          qloadi,qloadfi)
  IF (ABS(nloadi) .LT. 0.1) THEN        ! --- Assume shaft is at rest
    nsrci = 0.0
```

```
    qsrci = 0.0
  ELSE
    nsrci = nloadi * mpid&z&gr

    ! ------------ Calc torque loss constant and initial torque loss
    !            on source shaft side
    cqlids&z& = (pctids&z& * qsrcb) / (nsrcb*nsrcb)
    qlids&z&i = cqlids&z& * nsrci * ABS(nsrci)
    ! ---------------- Calc initial source shaft torque
    qsrci = qlids&z&i + (qloadi+qloadfi) / mpid&z&gr
  ENDIF
END    ! --- of PROCEDURAL
END !  ++++++++++++ of INITIAL

! +++++++ Begin DERIVATIVE Section +++++++++++++++++++++++++++++++++++

! ---------------- Calc LOAD shaft speed (accel) in units of
!          RPM (RPM/SEC)
qlids&z& = cqlids&z& * nsrc * ABS(nsrc)   ! source shaft loss torque
delqzgr = (qsrc-qlids&z&)*mpid&z&gr - qload
qs&z&fgr = RSW (lstukzgr,-delqzgr, qlsfgr)
dnload = (rpmrad / iimpid&z&) * (delqzgr + qs&z&fgr)
nload = INTEG (dnload, nloadi)
ngrlzpu = nload / nloadb          ! --- per unit gearbox shaft speed

! ---------------- Check gearbox load shaft condition for shaft
!           stuck condition
chkgr&z&ls = RSW (lstukzgr, ABS(delqzgr) - qloadsbf, nload)
SCHEDULE shaft&z& .XZ. chkgr&z&ls
! ---------------- Calc SOURCE shaft speed (accel) in units of
!          RPM (RPM/SEC)
dnsrc = dnload * mpid&z&gr
nsrc = nload * mpid&z&gr
MACRO END

MACRO  shaftstk (z,qloadbf,nloadi,delqzgr,qloadf,qlsfgr,lstukzgr,nload)
!   inputs:          z = concatenation variable (1, 2, gl, etc)
!            qloadbf = load shaft breakaway friction torque [LB-FT]
!             nloadi = output  shaft initial speed [RPM]
!            delqzgr =
!             qloadf = load shaft rotating friction torque [LB-FT]
!
!   outputs:  qlsfgr = load shaft friction torque [LB-FT]
!           lstukzgr = logical (= .T. if shaft stuck)
  DISCRETE shaft&z&
! ---------------- Handle shaft sticking friction
    INITIAL
      LOGICAL   lstukzgr
      lstukzgr = ABS(nloadi) .LT. 0.1
    END
    ! ---------- Stuck flag toggles unless force exceeds breakout
    !            force on crossing zero
    lstukzgr = (.NOT. lstukzgr) .AND. (ABS(delqzgr) .LT. qloadbf)
    ! ---------- Determine shaft friction for stuck or rotating
    !            condition (sign of qloadf pre-determined in table)
```

```
    qlsfgr = RSW (lstukzgr, 0.0, qloadf)
    ! ---------- Reset shaft speed exactly to zero
    nload = 0.0
    ! ---------- Record status
    CALL LOGD (.TRUE.)
  END  ! of DISCRETE stick&z&gr
MACRO END  ! of shaftstk
!  >>>>>>>>  End Source/Load Interface Dynamics Model MACRO  <<<<<<<<<
!  ---------------------------------------------------------------------

!  ==================================================================
!  >>>>>>  Begin Seaway Dynamics Model MACRO  <<<<<<
!  ==================================================================
!   file name:  seaway1.mac clp 11-sep-91
!
!   This program models seaway hydrodynamic characteristics
!   for a ship hull moving through the water in one degree of
!   freedom.  It assumes that ship speed is normalized and that
!   nominal values for the seaway conditions are those given in
!   the original GE RFP spec.  This model has the capability
!   to simulate a variation in the frequency of wave encounter
!   based on the relative speed between the ship and the seaway.
!
!   This approach is patterned after method given in the original
!   GE RFP spec -- on page 20, wherein:
!
!       Ve = Vm * (1 - We * sin(2*pi*t/T)).
!
!   This program calculates the value of:
!
!       wesea = We * sin(2*pi*t/T)
!
!   and outputs wesea to the ship velocity equation in the model
!   ship1A.mac.
!
!   The following numerical data is given in [3], based on
!   Vm (mean ship speed):
!
!       T (period, sec)       6       10      15
!
!       We (moderate seas)   0.10    0.12    0.13
!
!       We (heavy seas)      0.40    0.47    0.50
!
!   To permit investigation of doppler frequency effects,
!   assume the following values for lambda (wavelength):
!
!       wavelength         4       12      25
!
!   For an initial case, assume T= 6, We= 0.10, and L= 4
!
!    Needs following parameters:
!
!            twopi
!
```

```
!    from:  /home/ra4/patterson/acsl/constants.mod
!
! -------------------------------------------------------------
!
! MODELING CONVENTIONS:
! ------------------
!
!  (1)  Use CAPS for ACSL statements, ACSL variables, etc.
!
!  (2)  Use lower case for all model variables.
!
!  (3)  Begin Table names, Function names and related control
!   variables with a capital letter.
!
! -------------------------------------------------------------
!
! CHANGE RECORD:
! ------------
!
! Version   Date    Engr    Description
! -------  -------  ----  ---------------------------------------
!    0     xxxxx91  clp   Model developed and installed.
!
!    1     20Aug92   ow   moved lsea and ldoppler to output list.
!
! --------------------------------------------------------------

   MACRO  seaway(z,lsea,ldoplr,vshippu,wesea)

!   inputs:         z = concatenation variable (1, 2, gl, etc)
!             vshippu = ship velocity normalized (per unit)
!
!   outputs:    wesea = seaway velocity factor [per unit]
!                lsea = logical flag set .TRUE. to invoke seaway
!            ldoppler = logical flag set .TRUE. to invoke an
!                       effective doppler seaway frequency

! ---------------- define basic constants for ship seaway dynamics

LOGICAL     lsea, ldoplr

CONSTANT    lsea = .FALSE., ldoplr = .FALSE.
CONSTANT    tsea = 6.0, wesmax = 0.10, wave = 4.0

! +++++++ Begin INITIAL Section ++++++++++++++++++++++++++++++++++++

INITIAL

! ---------------- calculate seaway encounter frequency [RAD/SEC]
!           based on tsea (constant frequency) and a
!           constant for computing doppler frequency

wefsea = twopi / tsea
kdfrq = twopi / wave
```

```
END !  ++++++++++++ of INITIAL

! +++++++ Begin DERIVATIVE Section ++++++++++++++++++++++++++++++++++++

! ---------------- calculate seaway velocity magnitude.  The REALPL
!            function has been included to smooth the
!            initial seaway encounter.
!
!       NOTE:  This code has been placed within a PROCEDURAL
!              to circumvent an ACSL implicit loop flag.
!              That is, when combined with "ship1A.mac",
!              the following expression occurs:
!
!                 vslpu =  INTEG() * (1 - wesea),
!
!              where,    wesea = f(vslpu,t)
!
!              To achieve the desired result, the variable
!              "vshippu" has been left out of the argument
!              list.

PROCEDURAL (wesea = lsea,ldoplr,wesmax)
  IF (.NOT. lsea) t0sea = 0.0
  IF (lsea .AND. (t0sea .EQ. 0.0)) t0sea = t
  weseamg = REALPL(tsea/5.0, RSW(lsea, wesmax, 0.0), 0.0)
  seafrq = RSW(ldoplr, kdfrq * ABS(vshippu + weseamg + 0.001), wefsea)
  seatime = RSW( lsea, (t - t0sea), 0.0)
  wesea = weseamg * SIN( seafrq*(seatime))
END  ! -- of PROCEDURAL

MACRO END

!  >>>>>>>>  End Source/Load Interface Dynamics Model MACRO  <<<<<<<<<
!  ------------------------------------------------------------------

!  ============================================================
!  >>>>>>  Begin Propeller/Ship Dynamics Model MACRO  <<<<<<
!  ============================================================
!   file name:  ship1A.mac  clp 23-aug-91
!
!   This program models the propeller and hydrodynamic
!   characteristics for a ship hull moving through the water
!   in one degree of freedom.  The simulated ship is that
!   represented by ship1 data.  The hull resistance, the
!   propeller torque, and the propeller thrust characteristics
!   have been normalized.  The characteristics (torque and thrust)
!   have been represented as functions of two variables (per unit
!   ship speed and per unit propeller shaft speed).  The ship hull
!   resistance function has been characterized using a 10th order
!   polynomial to fit the available data for the full AHEAD/ASTERN
!   maneuvering range.  This model also includes the friction torque
!   function for the propeller shafts associated with the ship hull.
!
!   The model assumes an initial ship speed (per unit) which can
!   be selected at run time.  Using this ship speed and the ship
```

```
!   resistance data table, a per unit shaft speed is calculated
!   and converted to shaft RPM to be output along with the base
!   RPM value.  It is assumed that the two propeller shafts are
!   operating at the same initial shaft speed.
!
!   To calculate headreach, set the logical flag lheadr = .TRUE.
!   A mode-controlled integrator is used to calculate headreach
!   in terms of per unit ship speed.  The ACSL SCHEDULE statement
!   is used to determine when the ship speed reaches zero.
!
!   Propeller shaft speed inputs are in RPM and the model is set
!   up to respond to a seaway input (wesea).  If a seaway is not
!   to be used, set wesea = 0.0. The function lookup table (Q1Apsf)
!   is used to calculate and output propeller shaft frictional
!   torque (LB-FT) as a function of shaft RPM.
!
!   This model requires the following files which contain
!   function data:
!
!       /models/hydro/TQ1Alib.a
!       /models/lookup/lookuplib.a
!
!    Needs following parameters:
!
!            rpmrad, gcons, khh2
!
!    from:  /home/ra4/patterson/acsl/constants.mod
!
!  -----------------------------------------------------------
!
!  MODELING CONVENTIONS:
!  -------------------
!
!  (1)  Use CAPS for ACSL statements, ACSL variables, etc.
!
!  (2)  Use lower case for all model variables.
!
!  (3)  Begin Table names, Function names and related control
!   variables with a capital letter.
!
!  -----------------------------------------------------------
!
!  CHANGE RECORD:
!  -------------
!
! Version   Date    Engr    Description
! -------  -------  ----  -------------------------------------
!    0      7oct91  clp   Model developed and installed.
!
!    1     18oct91  clp   Added hhps inertia calculation
!
!    2
!
! -------------------------------------------------------------
MACRO  ship1a(z,np1rpm,np2rpm,wesea,lheadr,jjps,np1rpmi,qp1i, &
```

```
                  qp1,qp1fi,qp1f,np2rpmi,qp2i,qp2,qp2fi,qp2f,vslpu, &
                   lcalchr,lvship0,headrpu,t0vship,tvship0,xvship0, &
                   qpsbaf,nprpmb,qpbase)

!   inputs:         z = concatenation variable (1, 2, g1, etc)
!         np1rpm = propeller shaft speed [RPM]
!         np2rpm = propeller shaft speed [RPM]
!          wesea = seaway velocity factor [per unit]
!         lheadr = logical ( = .T. to begin headreach calc)
!
!   outputs:     jjps = total prop/shaft inertia [LB-FT^2]
!        np1rpmi = initial shaft speed [RPM]
!           qp1i = initial shaft torque [LB-FT]
!            qp1 = shaft torque [LB-FT]
!          qp1fi = initial shaft frictional loss torque [LB-FT]
!           qp1f = shaft frictional loss torque [LB-FT]
!        np2rpmi = initial shaft speed [RPM]
!           qp2i = initial shaft torque [LB-FT]
!            qp2 = shaft torque [LB-FT]
!          qp2fi = initial shaft frictional loss torque [LB-FT]
!           qp2f = shaft frictional loss torque [LB-FT]
!          vslpu = per unit ship speed
!        lcalchr = logical ( = .T. to permit headreach calc)
!        lvship0 = logical ( SCHEDULE flag = .T. when vs=0.0)
!        headrpu = headreach on vsl per unit base
!        t0vship = time at which headreach calc starts
!        tvship0 = time req'd to stop ship from start of headr
!        xvship0 = headreach distance on vsl per unit base
!         qpsbaf = propeller shaft breakaway friction [LB-FT]
!         nprpmb = propeller shaft speed base [RPM]
!         qpbase = propeller shaft torque base [LB-FT]
! ---------------- define logical variables

LOGICAL     lheadr
!---LOGICAL     lcalchr
! --- lvship0 handled by SCHEDULE

CONSTANT    lheadr = .FALSE.

! ---------------- define basic propeller constants

CONSTANT    qpbase = 1239071.4
CONSTANT    nprpmb = 144.7185
CONSTANT    nprpsb = 2.4120      !---shaft RPS base
CONSTANT    jjprop = 1313000     !---inertia w/ 25 pct H2O [LB-FT^2]
CONSTANT    jjshft = 166000      !---shaft inertia [LB-FT^2]

! ---------------- define reference values for time and distance to
!           stop ship.  Based on cutting motor torque to a
!           value of 0.0 per unit at a rate of -1.0 pu/sec.
!           The coastdown from vslpu = 1.0 per unit ship
!           speed until 0.1 pu propeller shaft speed is
!           reached.  Then apply -0.5 pu motor torque at a
!           rate of -1.0 pu/sec.
```

```
CONSTANT    tvs0ref = 696.262 , xvs0ref = 207.220

! ---------------- define basic constants for ship hull dynamics

CONSTANT    k10res = -15.1636679
CONSTANT    k09res =  20.3594595
CONSTANT    k08res =  15.9458303
CONSTANT    k07res = -23.5962574
CONSTANT    k06res = - 5.1990814
CONSTANT    k05res =   8.6572075
CONSTANT    k04res = - 0.2317509
CONSTANT    k03res =   0.9698059
CONSTANT    k02res = - 0.0573738
CONSTANT    k01res =   0.2023390
CONSTANT    k00res =   0.0000000
CONSTANT    kvship = 0.0075497
! --- per unit conversion factor

! +++++++ Begin INITIAL Section +++++++++++++++++++++++++++++++++++

INITIAL
! ---------------- calculate combined propeller/shaft inertia

jjps = jjprop + jjshft          ! --- WR^2 form

hhps = khh2 * (jjps * nprpmb / qpbase)

! ---------------- calculate shaft breakaway friction [LB-FT]

qpsbaf = QlApsf(0.0)

! ---------------- set initial ship speed (per unit)

CONSTANT   vslpui = 0.0
CONSTANT   vslpu0 = 0.00001   ! use when calculating T/Q for Vs==0.0

! ---------------- calculate initial ship resistance (per unit)

vslpu2i  =  vslpui * vslpui
vslpu3i  = vslpu2i * vslpui
vslpu4i  = vslpu3i * vslpui
vslpu5i  = vslpu4i * vslpui
vslpu6i  = vslpu5i * vslpui
vslpu7i  = vslpu6i * vslpui
vslpu8i  = vslpu7i * vslpui
vslpu9i  = vslpu8i * vslpui
vslpu10i = vslpu9i * vslpui

rslpui0 = k10res * vslpu10i + k09res * vslpu9i + k08res * vslpu8i
rslpui1 = k07res * vslpu7i  + k06res * vslpu6i + k05res * vslpu5i
rslpui2 = k04res * vslpu4i  + k03res * vslpu3i + k02res * vslpu2i
rslpui3 = k01res * vslpui   + k00res
rslpui = rslpui0 + rslpui1 + rslpui2 + rslpui3

! ---------------- calculate initial propeller thrust (per unit)
```

```
tp1pui = rs1pui / 2.0
tp2pui = tp1pui

! ---------------- calculate initial prop rpm, torque and shaft
!            loss torque for each propeller

PROCEDURAL (np1rpmi, np1pui, qp1i, qp1pui = vs1pui, tp1pui)

  IF (vs1pui .LT. 0.0) THEN     ! --- use functions for reverse Vs
    np1pui = T1Avsr(0.0, vs1pui, tp1pui, Fargs1)
    np1rpmi = np1pui * nprpmb
    qp1pui = Q1Avsr(np1pui, vs1pui, 0.0 , Fargs0)
    qp1i = qp1pui * qpbase
  ELSEIF (vs1pui .EQ. 0.0000) THEN    !---use functions for forward Vs
    np1pui = T1Avsf(0.0, vs1pu0, tp1pui, Fargs1)
    np1rpmi = np1pui * nprpmb
    qp1pui = Q1Avsf(np1pui, vs1pu0, 0.0 , Fargs0)
    qp1i = qp1pui * qpbase
  ELSE                          ! --- use functions for forward Vs
    np1pui = T1Avsf(0.0, vs1pui, tp1pui, Fargs1)
    np1rpmi = np1pui * nprpmb
    qp1pui = Q1Avsf(np1pui, vs1pui, 0.0 , Fargs0)
    qp1i = qp1pui * qpbase
  ENDIF

END  ! --- of PROCEDURAL

np2pui = np1pui
np2rpmi = np1rpmi
qp2pui = qp1pui
qp2i = qp1i

qp1fi = Q1Apsf(np1rpmi)        ! shaft frictional loss torque
qp2fi = Q1Apsf(np2rpmi)

END !  ++++++++++++ of INITIAL

! +++++++ Begin DERIVATIVE Section ++++++++++++++++++++++++++++++++++

! ---------------- calculate thrust and torque for both propellers

np1pu = np1rpm / nprpmb
np2pu = np2rpm / nprpmb

IF (vs1pu .LT. 0.0) THEN       ! --- use functions for reverse Vs
    ! ---- prop shaft 1
  tp1pu = T1Avsr(np1pu, vs1pu, 1.0, Fargs0)
  qp1pu = Q1Avsr(np1pu, vs1pu, 1.0, Fargs0)
    ! ---- prop shaft 2
  tp2pu = T1Avsr(np2pu, vs1pu, 1.0, Fargs0)
  qp2pu = Q1Avsr(np2pu, vs1pu, 1.0, Fargs0)
ELSEIF (vs1pu .EQ. 0.0000) THEN    ! --- use functions for forward Vs
    ! ---- prop shaft 1
  tp1pu = T1Avsf(np1pu, vs1pu0, 1.0, Fargs0)
```

```
  qp1pu = Q1Avsf(np1pu, vs1pu0, 1.0, Fargs0)
      ! ---- prop shaft 2
  tp2pu = T1Avsf(np2pu, vs1pu0, 1.0, Fargs0)
  qp2pu = Q1Avsf(np2pu, vs1pu0, 1.0, Fargs0)
 ELSE                          ! --- use functions for forward Vs
      ! ---- prop shaft 1
  tp1pu = T1Avsf(np1pu, vs1pu, 1.0, Fargs0)
  qp1pu = Q1Avsf(np1pu, vs1pu, 1.0, Fargs0)
      ! ---- prop shaft 2
  tp2pu = T1Avsf(np2pu, vs1pu, 1.0, Fargs0)
  qp2pu = Q1Avsf(np2pu, vs1pu, 1.0, Fargs0)
ENDIF

qp1 = qp1pu * qpbase
qp2 = qp2pu * qpbase
qp1f = Q1Apsf(np1rpm)       ! --- shaft frictional torque loss
qp2f = Q1Apsf(np2rpm)
! ---------------- calculate ship resistance

vs1pu2  =  vs1pu * vs1pu
vs1pu3  = vs1pu2 * vs1pu
vs1pu4  = vs1pu3 * vs1pu
vs1pu5  = vs1pu4 * vs1pu
vs1pu6  = vs1pu5 * vs1pu
vs1pu7  = vs1pu6 * vs1pu
vs1pu8  = vs1pu7 * vs1pu
vs1pu9  = vs1pu8 * vs1pu
vs1pu10 = vs1pu9 * vs1pu

rs1pu0 = k10res * vs1pu10 + k09res * vs1pu9 + k08res * vs1pu8
rs1pu1 = k07res * vs1pu7 + k06res * vs1pu6 + k05res * vs1pu5
rs1pu2 = k04res * vs1pu4 + k03res * vs1pu3 + k02res * vs1pu2
rs1pu3 = k01res * vs1pu + k00res
rs1pu = rs1pu0 + rs1pu1 + rs1pu2 + rs1pu3

! ---------------- calculate ship speed (per unit) with seaway
!           effects included

vs1pu = INTEG( kvship * (tp1pu + tp2pu - rs1pu), vs1pui )  &
           * ( 1 - wesea)

! ---------------- Calculate headreach to the point at which
!           ship speed goes to zero.
!
!   ------ The following PROCEDURAL insures that lheadr .AND.
!        lcalchr are .NOT. simultaneously .FALSE. since that
!        condition would cause unwanted calculation of headrpu.
!        It also updates t0vship until lheadr=.TRUE. to set
!        the start time for the headreach calculation.

!---PROCEDURAL (lcalchr, tovship = lheadr)
!---  IF (.NOT. lheadr) THEN
!---      lcalchr = .TRUE.
!---      lvship0 = .FALSE.
!---      t0vship = T
```

```
!---  ENDIF
!---END   ! of PROCEDURAL

!          lcalchr     lheadr      mode    operation
!          ----------------------------------------------
!           true        false       ic       set headreach = 0.0
!           false       false       op
!           true        true        op       calculate headreach
!           false       true       hold      hold headreach value


!---headrpu = MODINT( vslpu, 0.0, lcalchr,lheadr ) !---scaled headreach

!---SCHEDULE stopvs/lvship0 .XZ. vslpu      ! --- Check for vslpu ==>
0.0

! ---------------- Calculate the percent time/distance to stop ship
!           with respect to the reference values.

!---tvs0pct = (tvship0 / tvs0ref) * 100
!---xvs0pct = (xvship0 / xvs0ref) * 100

! ---------------- Calculate the percent values for prop shaft
!           speed/torque,ship speed, headreach (wrt xvs0ref)
!           and time for plotting purposes

!---pctnp1 = np1pu * 100
!---pctqp1 = qp1pu * 100
!---pctnp2 = np2pu * 100
!---pctqp2 = qp2pu * 100
!---pctvs1 = vslpu * 100
!---pcthdr = (headrpu / xvs0ref) * 100
!---pcttim = (t / tvs0ref) * 100

! ---------------- Terminate the simulation run when shaft speed or
!           ship speed exceeds MAX/MIN values for data
!           in function lookup tables.

TERMT (vslpu .GT. 1.1,  &
       '  Run Terminated ==>  Ship speed exceeded MAX value')
TERMT (vslpu .LT. -0.7,  &
       '  Run Terminated ==>  Ship speed exceeded MIN value')
TERMT (np1pu .GT. 1.16,  &
 'Run Terminated ==>  Prop shaft RPM exceeded Qfrict MAX value')
TERMT (np1pu .LT. -1.0,  &
 'Run Terminated ==>  Prop shaft speed exceeded T/Q MIN value')

MACRO END

!---MACRO  stopvs(z,lheadr,lcalchr,lvship0,headrpu, &
!---              t0vship,tvship0,xvship0)

!---  DISCRETE stopvs

!---    IF (lheadr .AND. lcalchr .AND. lvship0) THEN
```

```
!---       lcalchr = .FALSE.
!---       tvship0 = T - t0vship
!---       xvship0 = headrpu
!---       CALL LOGD(.TRUE.)
!---     ENDIF

!---   END  ! of DISCRETE stopship

!---MACRO END

!  >>>>>>>>  End Propeller/Ship Dynamics Model MACROs  <<<<<<<<<
!  -----------------------------------------------------------------
```

A.20 Motor Controller

```
!-----------------------------------------------------------------
!
!                              Motor Controller
!
!                     Copyright 1993 by Timothy J. McCoy
!
!=================================================================
!                              Record of Changes
!
!  No.  Date     By      Summary
!  ---  ------  ---     ------------------------------------------
!   0   3-22-93 tjm     Model written.
!   1   4-13-93 tjm     Added control of firing angle.
!=================================================================
!   macro: contmtr.mac
!   function:  controlls motor excitation and inverter firing angle
!                              CONCATENATION
!   z          = motor identifier
!
!                              INPUTS
!   id         = D-axis stator current [per unit]
!   iq         = Q-axis stator current [per unit]
!   vd         = D-axis stator voltage [per unit]
!   vq         = Q-axis stator voltage [per unit]
!   xdmxq      = difference between D and Q-axis synchronous reactances
!   xq         = Q-axis synchronous reactance [per unit]
!
!                              OUTPUTS
!   eaf        = motor excitation [per unit]
!   betai      = inverter firing angle [rad]
!
!                              CONSTANTS
!   eis&z&     = desired stator flux linkage [per unit]
!   eaf&min    = minimum excitation voltage [per unit]
!   eaf&max    = maximum excitation voltage [per unit]
!   eaf&ic     = excitation voltage initial condition [per unit]
!   geaf&z     = field excitation controller gain
!   taueaf&z   = field excitation controller time constant
!   beta&min   = minimum inverter firing angle [rad]
!   beta&max   = maximum inverter firing angle [rad]
```

```
!   beta&ic    = inverter firing angle initial condition [rad]
!   gbeta&z    = inverter firing angle controller gain
!   taubeta&z  = inverter firing angle controller time constant
!   phis&z&    = desired power factor angle [rad]
!
!================(must be defined in the calling program)==========
!               Defined in 'constant.inc'
!   k2rt3opi   = 2*sqrt(3)/pi
!   kpi        = pi = 3.141592654
!
!                              INTERNAL
!   vt&z&      = motor terminal voltage [per unit]
!   ia&z&      = motor terminal current [per unit]
!   del&z&     = motor torque angle [rad]
!   phi&z&     = motor power factor angle [rad]
!   iajxq&z&   = round rotor component of synchronous reactance
!                voltage drop
!   ids&z&     = D-axis component of stator current calculated from
!                desired link current
!   idx&z&     = saleint component of synchronous reactance
!                voltage drop
!   ep&z&      = desired field excitation from round rotor phasor
!                diagram
!   eafs&z&    = desired field excitation, including saliency
!   eaferr&z&  = error in field excitation
!   eafd&z&    = time derivative of field excitation
!   betas&z&   = desired inverter firing angle
!   betaerr&z&= error in inverter firing angle
!   beta&z&d   = time derivative of inverter firing angle
!
!=================================================================

MACRO contmtr (eaf,betai , &
               id,iq,vd,vq,edpp,eqpp,xdpp,xdmxq,xq,lbrake,z)
!=================================================================
!                 Begin Derivative Section
!=================================================================
!---parameters
CONSTANT eis&z&     = 1.0
CONSTANT eaf&min    = 0.0
CONSTANT eaf&max    = 4.0
CONSTANT geaf&z&    = 100.0
CONSTANT taueaf&z&  = 0.1
CONSTANT eaf&ic     = 1.0
CONSTANT betamin&z& = kpio2
!---CONSTANT betamax&z& = 3.14
!---CONSTANT beta&z&ic  = 3.13
!---CONSTANT gbeta&z&   = 1.0
! ---CONSTANT taubeta&z& = 0.1
CONSTANT beta&z& = 2.2
CONSTANT phis&z= 0.2

!---Calculation of desired excitation
!---(solution of phasor diagram)
RTP( vt&z&,del&z& = vq,vd)
```

```
RTP( ia&z&,phip&z& = iq,id)
iajxq&z = ia&z&*xq
idx&z&  = ABS(id*xdmxq)
ep&z&   = SQRT(eis&z&**2 + iajxq&z&**2 + &
          2.0*eis&z&*iajxq&z&*SIN(kpio2 + phis&z&))
eafs&z& = ep&z& + idx&z

!---field flux error signal
eaferr&z= eafs&z& - eaf

!---P-I type controller on field excitation
eaf&d   = (geaf&z&*(eaferr&z&))/taueaf&z
eaf     = BOUND(eaf&min,eaf&max,LIMINT(eaf&d,eaf&ic,eaf&min,eaf&max))

!---calculation of desired inverter firing angle
!---betas&z = kpi - ABS(del&z&) - phis&z

!---error in inverter firing angle
!---betaerr&z= betas&z& - betai

!---P-I type controller on inverter firing angle
!---beta&z&d = (gbeta&z*(betaerr&z&))/taubeta&z
!---beta&z&  = BOUND(betamin&z,betamax&z,LIMINT(beta&z&d,&
!---               beta&z&ic,betamin&z,betamax&z))

IF(lbrake)THEN
    betai    = betamin&z
ELSE
    betai    = beta&z
ENDIF
MACRO END !---of contmtr
```

A.21 Speed Controller

```
!=====================================================================
!
!                     MOTOR SPEED CONTROLLER MODEL
!
!                           Copyright 1993
!                                 by
!                          Timothy J. McCoy
!
!=====================================================================
!
!    macro:     speedcon
!    function:  motor speed control, P-I type controller.
!
!                            CONCATENATION
!   z           =  frequency changer identifier
!
!                               INPUTS
!   spdref      =  reference speed [per unit]
!   wrn         =  motor speed [per unit]
!
!                              OUTPUTS
```

```
!   idcr         =  dc link reference current  [PER UNIT]
!   lfwd         =  logical variable indicating forward torque
!
!                                  CONSTANTS
!   gspeed&z&    = Controller Amplitude
!   tauspeed&z& = Controller Time Constant
!   idcr&min     = minimum dc link current [per unit]
!   idcr&max     = maximum dc link current [per unit]
!
!                                  INTERNAL
!   idcr&ic      = dc link current ic
!   idcr&d       = dc link current derivative
!   speederr&z& = speed error
!=====================================================================
MACRO speedcon (idcr,lfwd,lbrake , spdref,wrn,idc,z)

!---parameters
CONSTANT idcr&ic    = 0.0
CONSTANT idcr&min   = 0.0
CONSTANT idcr&max   = 1.0
CONSTANT idcr&dmax  = 5.0
CONSTANT idcr&dmin  = -5.0
CONSTANT spderr&z&ic = 0.0
CONSTANT dz&z&      = 0.05
CONSTANT threshold&z= 0.1
CONSTANT taufast&z& = 0.1
CONSTANT glarge&z&  = 50.0
CONSTANT tauslow&z& = 20.0
CONSTANT gsmall&z&  = 5.0

!---Speed control
IF (spdref .LT. 0.0) THEN
    lfwd = .FALSE.
    speederr&z& = -(spdref - wrn)
ELSE
    lfwd = .TRUE.
    speederr&z& = (spdref - wrn)
ENDIF

switchvar&z = BCKLSH(spderr&z&ic,dz&z&,speederr&z&)

IF (ABS(switchvar&z&).GT.threshold&z&) THEN
    tauspeed&z = taufast&z
    gspeed&z&  = glarge&z
ELSE
    tauspeed&z = tauslow&z
    gspeed&z&  = gsmall&z
ENDIF

IF((SIGN(1.0,spdref).NE.SIGN(1.0,wrn)).AND.(wrn.GT.0.06))THEN
    kbrake&z = 0.0
    IF((idc .LT. 0.05).AND.(.NOT.lbrake)) lbrake = .true.
ELSE
    IF((wrn .LE. 0.04).AND.(lbrake)) lbrake = .false.
    kbrake&z = 1.0
```

```
ENDIF

idcr&d   = BOUND(idcr&dmin,idcr&dmax, &
           (-idcr + gspeed&z&*(speederr&z&))/tauspeed&z)
idcom&z = BOUND(idcr&min,idcr&max, &
           LIMINT(idcr&d,idcr&ic,idcr&min,idcr&max))
idcr     = idcom&z&*kbrake&z

MACRO END !---of speedcon
```

A.22 Synchronous Motor

```
!-----------------------------------------------------------------
!
!                THREE-PHASE SYNCHRONOUS MOTOR MODEL
!                 written in generator coordinates
!
!                Copyright 1993 by Timothy J. McCoy
!
!=================================================================
!                           Record of Changes
!
!  No.  Date    By      Summary
!  ---  ------  ---     ------------------------------------------
!   0   1-28-93 tjm     Model written.
!   1   2-14-93 tjm     Removed delta from argument list.
!   2   2-19-93 tjm     Revised definitions of vd & vq to correct
!                       error in derivation.
!   3   2-20-93 tjm     Changed currents to generator coordinates.
!   4   3-27-93 tjm     Removed calculation of delta
!   5   4-10-93 tjm     Revised voltage calculation to account for
!                       speed variation.
!=================================================================
!
!    macro:     symmtr4
!    function:  Models a three-phase synchronous motor
!               with stator resistance and electric
!               transients neglected.
!
!                             CONCATENATION
!   z        = synchronous machine identifier
!
!                               INPUTS
!   wrn      = Machine speed [per unit]
!   iq       = Q-axis stator current in rotor frame [per unit]
!   id       = D-axis stator current in rotor frame [per unit]
!   eaf      = Field excitation [per unit]
!   tm       = Mechanical torque [per unit]
!
!                               OUTPUTS
!   vq       = Q-axis stator voltage in rotor reference frame
!   vd       = D-axis stator voltage in rotor reference frame

!   te       = Electrical torque [per unit]
!   wrn      = Rotor speed [per unit]
!
```

```
!                              CONSTANTS
!
!=================(must be defined in the calling program)===========
!
!   wo         = base electrical speed [rad/sec]
!   xq&z       = Q-axis synchronous reactance [per unit]
!   xd&z       = D-axis synchronous reactance [per unit]
!   xqpp&z     = Q-axis subtransient reactance reactance [per unit]
!   xdpp&z     = D-axis subtransient reactance reactance [per unit]
!   xdp&z      = D-axis transient reactance [per unit]
!   xl&z       = Armature leakage reactance [per unit]
!   tdop&z     = D-axis transient open circuit time constant [per unit]
!   tdopp&z    = D-axis subtransient open circuit time constant [per unit]
!   tqopp&z    = Q-axis subtransient open circuit time constant [per unit]
!   h&z&       = Rotor inertia [sec]
!              = J*wo/(Tb*P)  P = # of poles
!===================(defined in macro mtr4ic)=======================
!   alpha&z   = (xd - xdpp)/(xdp - xdpp)
!
!                        INTERNAL (STATE OR STATE RELATED)
!   wm&z&      = rotor speed [rad/sec]
!   delta      = Rotor electrical angle [rad]
!   eqpp&z     = Q-axis voltage behind subtransient reactance [per unit]
!   edpp&z     = D-axis voltage behind subtransieng reactance [per unit]
!   eqp&z      = Q-axis voltage behind transient reactance [per unit]
!
!                          INTERNAL (NOT STATE RELATED)
!
!   Defined in macro synmtric() located in this file.
!   wm&z&ic    = rotor mechanical speed ic [rad/sec]
!   delta&z&ic= rotor angle ic [rad]
!   eqpp&z&ic = eqpp ic [per unit]
!   edpp&z&ic = edpp ic [per unit]
!   eqp&z&ic  = eqp ic [per unit]
!
!   Defined in macro excitmtr().
!   eaf&ic     = field excitation initial condition
!
!-------This model requires a separate exciter for the field winding.
!
!=====================================================================
MACRO synmtr4 (te,vq,vd,wrn , eaf,iq,id,tm,z)
!=====================================================================
!                    Begin Derivative Section
!=====================================================================

!---Compute Electromagnetic Torque
!---(positive for motor action)
    te      = (-eqpp&z&*iq - edpp&z&*id + (xdpp&z& - xqpp&z&)*id*iq)

!---Rate of change of rotor speed
    wm&z&d  = (te + tm)*wo/(2*h&z&)

!---Rates of Change of state variables
    eqpp&z&d = (eqp&z& - eqpp&z& - (xdp&z& - xdpp&z&)*id)/tdopp&z
```

```
    edpp&z&d = (-edpp&z& + (xq&z& - xqpp&z&)*iq)/tqopp&z
    eqp&z&d  = (-alpha&z&*eqp&z& + &
               (alpha&z& - 1.0)*eqpp&z& + eaf)/tdop&z

!---integrate to obtain flux linkages, speed and rotor angle.
    eqpp&z& = INTEG(eqpp&z&d,eqpp&z&ic)
    edpp&z& = INTEG(edpp&z&d,edpp&z&ic)
    eqp&z&  = INTEG(eqp&z&d,eqp&z&ic)
    wm&z&   = INTEG(wm&z&d,wm&z&ic)
    thm&z&  = INTEG(wm&z&,thm&z&ic)
!---    delta&z = INTEG(wm&z& - wo,delta&z&ic)

!---Compute voltages in terms of state variables
    vq  = wrn*(eqpp&z& - xdpp&z&*id)
    vd  = wrn*(edpp&z& + xqpp&z&*iq)

!---Compute per unit speed for output
    wrn     = wm&z& / wo

!=====================================================================
!                 End of Derivative Section
!=====================================================================
MACRO END ! of synmtr4

!---------------------------------------------------------------------
!
!       THREE-PHASE SYNCHRONOUS MOTOR INITIALIZATION MODEL
!
!              Copyright 1992 by Timothy J. McCoy
!
!=====================================================================
!                          Record of Changes
!
! No.  Date     By      Summary
! ---  ------   ---     ----------------------------------------
!  0  1-28-92  tjm     Model written.
!
!=====================================================================
!
!    macro:     mtr4ic
!    function:  Initializes varous parameters for use with the
!               synchronous motor model synmtr4.
!
!                             CONCATENATION
!       z       = synchronous machine identifier
!
!=====================================================================
MACRO mtr4ic(z)

!---Initialize rotor reference angle
!---    CONSTANT delta&z&ic = 0.0
    CONSTANT thm&z&ic = 0.0

!---Calculate paramater alpha
    alpha&z&  = (xd&z& - xdpp&z&)/(xdp&z& - xdpp&z&)
```

```
!---Assume motor initially at rated speed
    CONSTANT wm&z&ic    = 377.0
    CONSTANT iq&z&ic    = 0.0
    CONSTANT id&z&ic    = 0.0
    edpp&z&ic = (xq&z& - xqpp&z&)*iq&z&ic
    eqp&z&ic  = -(alpha&z& - 1.0)*(xdp&z& - xdpp&z&)*id&z&ic &
              + eaf&z&ic
    eqpp&z&ic = eqp&z&ic - (xdp&z& - xdpp&z&)*id&z&ic

MACRO END ! of synmtric
```

A.23 Synchronous Generator

```
!-----------------------------------------------------------------------
!
!               THREE-PHASE SYNCHRONOUS GENERATOR MODEL
!                written in generator coordinates
!
!               Copyright 1993 by Timothy J. McCoy
!
!=======================================================================
!                          Record of Changes
!
!  No.  Date     By      Summary
!  ---  ------   ---     ----------------------------------------
!   0   1-28-93  tjm     Model written.
!   1   2-14-93  tjm     Removed delta from argument list.
!   2   2-19-93  tjm     Revised definitions of vd & vq to correct
!                        error in derivation.
!   3   2-20-93  tjm     Changed currents to generator coordinates.
!   4   3-27-93  tjm     Removed calculation of delta
!   5   4-9-93   tjm     Revision "b" removed mechanical equations for
!                        use with gas turbine model.
!=======================================================================
!
!    macro:     synmtr4b
!    function:  Models a three-phase synchronous motor
!               with stator resistance and electric
!               transients neglected.
!
!                             CONCATENATION
!   z         = synchronous machine identifier
!
!                               INPUTS
!   wrn       = Machine speed [per unit]
!   iq        = Q-axis stator current in rotor frame [per unit]
!   id        = D-axis stator current in rotor frame [per unit]
!   eaf       = Field excitation [per unit]
!
!                               OUTPUTS
!   vq        = Q-axis stator voltage in rotor reference frame
!   vd        = D-axis stator voltage in rotor reference frame

!   te        = Electrical torque [per unit]
```

```
!
!                              CONSTANTS
!
!================(must be defined in the calling program)==========
!
!   wo       = base electrical speed [rad/sec]
!   xq&z     = Q-axis synchronous reactance [per unit]
!   xd&z     = D-axis synchronous reactance [per unit]
!   xqpp&z   = Q-axis subtransient reactance reactance [per unit]
!   xdpp&z   = D-axis subtransient reactance reactance [per unit]
!   xdp&z    = D-axis transient reactance [per unit]
!   xl&z     = Armature leakage reactance [per unit]
!   tdop&z   = D-axis transient open circuit time constant [per unit]
!   tdopp&z  = D-axis subtransient open circuit time constant [per unit]
!   tqopp&z  = Q-axis subtransient open circuit time constant [per unit]
!==================(defined in macro mtr4ic)======================
!   alpha&z  = (xd - xdpp)/(xdp - xdpp)
!
!                    INTERNAL (STATE OR STATE RELATED)
!   eqpp&z   = Q-axis voltage behind subtransient reactance [per unit]
!   edpp&z   = D-axis voltage behind subtransieng reactance [per unit]
!   eqp&z    = Q-axis voltage behind transient reactance [per unit]
!
!                      INTERNAL (NOT STATE RELATED)
!
!   Defined in macro synmtric() located in this file.
!   eqpp&z&ic = eqpp ic [per unit]
!   edpp&z&ic = edpp ic [per unit]
!   eqp&z&ic  = eqp ic [per unit]
!
!   Defined in macro excitmtr().
!   eaf&ic     = field excitation initial condition
!
!-------This model requires a separate exciter for the field winding.
!
!=================================================================
MACRO synmtr4b (te,vq,vd , eaf,iq,id,wrn,z)
!=================================================================
!                 Begin Derivative Section
!=================================================================

!---Compute Electromagnetic Torque
!---(positive for motor action)
    te      = (-eqpp&z&*iq - edpp&z&*id + (xdpp&z& - xqpp&z&)*id*iq)

!---Rates of Change of state variables
    eqpp&z&d = (eqp&z& - eqpp&z& - (xdp&z& - xdpp&z&)*id)/tdopp&z
    edpp&z&d = (-edpp&z& + (xq&z& - xqpp&z&)*iq)/tqopp&z
    eqp&z&d  = (-alpha&z&*eqp&z& + &
                (alpha&z& - 1.0)*eqpp&z& + eaf)/tdop&z

!---integrate to obtain flux linkages, speed and rotor angle.
    eqpp&z& = INTEG(eqpp&z&d,eqpp&z&ic)
    edpp&z& = INTEG(edpp&z&d,edpp&z&ic)
    eqp&z&  = INTEG(eqp&z&d,eqp&z&ic)
```

```
!---Compute voltages in terms of state variables
    vq  = (eqpp&z& - xdpp&z&*id)
    vd  = (edpp&z& + xqpp&z&*iq)

!======================================================================
!                End of Derivative Section
!======================================================================
MACRO END ! of synmtr4

!----------------------------------------------------------------------
!
!        THREE-PHASE SYNCHRONOUS MOTOR INITIALIZATION MODEL
!
!              Copyright 1992 by Timothy J. McCoy
!
!======================================================================
!                         Record of Changes
!
!  No.  Date    By      Summary
!  ---  ------  ---     -------------------------------------------
!   0  1-28-92  tjm     Model written.
!
!======================================================================
!
!    macro:     mtr4bic
!    function:  Initializes varous parameters for use with the
!               synchronous motor model synmtr4.
!
!                           CONCATENATION
!       z       = synchronous machine identifier
!
!======================================================================
MACRO mtr4bic(z)

!---Calculate paramater alpha
    alpha&z&  = (xd&z& - xdpp&z&)/(xdp&z& - xdpp&z&)

!---Assume motor initially at rated speed
    CONSTANT iq&z&ic   = 0.0
    CONSTANT id&z&ic   = 0.0
    edpp&z&ic = (xq&z& - xqpp&z&)*iq&z&ic
    eqp&z&ic  = -(alpha&z& - 1.0)*(xdp&z& - xdpp&z&)*id&z&ic &
                + eaf&z&ic
    eqpp&z&ic = eqp&z&ic - (xdp&z& - xdpp&z&)*id&z&ic

MACRO END ! of synmtric
```

A.24 Voltage Regulator

```
!---------------------------------------------------------------------
!
!                GENERATOR VOLTAGE REGULATOR MODEL
!
!                Copyright 1992 by Timothy J. McCoy
```

```
!
!----------------------------------------------------------------
!   macro: vreg2.mac
!   function:  Limited PI type voltage regulator for a
!              synchronous generator.
!              This model comes from section 2.4 of notes from 6.686.
!
!   concatenation:
!       z        = generator exciter identifier
!
!   inputs:
!       vd       = D-axis terminal voltage [per unit]
!       vq       = Q-axis terminal voltage [per unit]
!
!    outputs:
!       eaf      = Generator exciter voltage [per unit]
!
!    constants:
!       vtref&z  = reference terminal voltage  [per unit]
!       geaf&z   = gain of exciter
!       taueaf&z = time constant of exciter
!       eaf&z&ic = ic for generator exciter voltage
!       eafmin&z = minimum value of excitation voltage [per unit]
!       eafmax&z = maximum value of excitation voltage [per unit]
!
!    internal:
!       eaf&z&d  = rate of change of exciter voltage
!       verr&z   = error voltage [per unit]
!    -----------------------------------------------------------
MACRO vreg2 (eaf , vd,vq,z)

!---parameters
    CONSTANT vtref&z = 1.001, geaf&z = 100.0, taueaf&z = 0.1, &
             eaf&ic = 1.0, eafmin&z = 0.0, eafmax&z = 3.0

RTP( vt&z&,del&z& = vq,vd)

verr&z&  = vtref&z-vt&z
eaf&d  = (-eaf + geaf&z*(verr&z&))/taueaf&z
eaf = BOUND(eafmin&z,eafmax&z,LIMINT(eaf&d,eaf&ic,eafmin&z,eafmax&z))

MACRO END ! of vreg2
```

Appendix B: Parameter Values

The following listing provides the parameter values used for the various components within the simulations.

B.1 Synchronous Machines

Parameter	18MVA Generator	2.5 MW Generator	20,000 HP Motor	Units
x_d	1.77	1.63	1.76	per unit
x_q	1.64	1.01	1.157	per unit
x_d''	0.15	0.18	0.542	per unit
x_q''	0.15	0.28	0.494	per unit
x_d'	0.18	0.25	0.608	per unit
x_l	0.13	0.075	0.337	per unit
t_{do}''	0.04	0.38	0.039	seconds
t_{qo}''	0.09	0.19	0.193	seconds
t_{do}'	3.19	3.79	2.1	seconds
H	0.92	1.91	0.773	seconds
ω_{base}	3,600	900	150	rpm
V_{base}	4,160	450	5,000	volts
P_{base}	16,200	2,500	14,914	Kw

B.2 Voltage Regulators

Parameter	18MVA Generator	2.5 MW Generator	20,000 HP Motor	Units
Gain	100	100	100	none
Time Constant	0.1	0.1	0.05	seconds

B.3 DC-link Current Controller

Gain: 30.0

Time Constant: 0.01 Seconds

B.4 Speed Controller

Parameter	Fast Mode	Slow Mode	Units
Gain	50	5	None
Time Constant	0.1	20	Seconds

B.5 Speed Governors

Parameter	Diesel	Gas Turbine	Units
Gain	5	0.5	None
Time Constant	2	3	Seconds

Appendix C: Two Motor Run

The following simulation run was made to show that the system would work properly with two frequency changer / motor combinations connected to the bus. In this simulation, both motor speed inputs and the ship speed start out at 0.5 per unit. This condition is held for 15 seconds to allow the speed governors on the prime movers to stabilize. At T=15 seconds, the #2 motor speed command is set to 0.9 per unit. As expected, the ship begins to accelerate. At T=30 seconds, motor #1 speed command is set to -0.5 per unit. This action causes the acceleration of the ship to cease. Eventually the ship speed stabilizes at about 0.6 per unit after 120 seconds. The following plots illustrate the first 40 seconds of the simulation. This is to show the electrical transients in the motors and generators as the speed command inputs are given the each respective motor. As with all previous simulations, the ship's service load is set to 0.2 per unit at 0.8 power factor lagging.

```
System #3:  Steady at 0.5 per unit load on both shafts
Listing of values

       T 160.000000       ZZTICG 0.                  CINT 0.10000000
  ZZIERR     F            ZZNBLK       1          ZZICON       0
  ZZSTFL      T           ZZFRFL     F            ZZICFL     F
  ZZRNFL     F            ZZJEFL     F            ZZNIST      49
  ZZNAST       0            IALG       1            NSTP      10
    MAXT 0.10000000         MINT 1.0000E-08

State Variables          Derivatives         Initial Conditions
  EDPPG1 0.10793700       Z99995-4.0735E-05      EDPPG1IC 0.
  EDPPG2 0.07827220       Z99992-3.7487E-05      EDPPG2IC 0.
  EDPPM1-0.09764770       Z99930 1.1096E-04      EDPPM1IC 0.
  EDPPM2-0.09764770       Z99925 1.1096E-04      EDPPM2IC 0.
  ENPTL1 7.19995000       Z99942 0.               ENPTL1I 7.20000000
   EQPG1 1.03021000       Z99994-1.0709E-04       EQPG1IC 1.00000000
   EQPG2 1.03484000       Z99991 5.5553E-05       EQPG2IC 1.00000000
   EQPM1 1.17462000       Z99929-2.4433E-04       EQPM1IC 1.00000000
   EQPM2 1.17462000       Z99924-2.4433E-04       EQPM2IC 1.00000000
  EQPPG1 1.02334000       Z99996-9.3806E-05      EQPPG1IC 1.00000000
```

EQPPG2	1.02266000	Z99993	3.0887E-05	EQPPG2IC	1.00000000
EQPPM1	1.16128000	Z99931	-2.4439E-04	EQPPM1IC	1.00000000
EQPPM2	1.16128000	Z99926	-2.4439E-04	EQPPM2IC	1.00000000
IDC1	0.22691600	Z99915	0.00218158	IDC1IC	0.
IDC2	0.22691600	Z99912	0.00218158	IDC2IC	0.
NGG1	7620.78000	Z99965	-0.24833000	NGG1I	7193.84000
NPT1	3599.98000	Z99978	-0.00255082	NPT1I	3600.00000
THMM1	24632.4000	Z99927	171.107000	THMM1IC	0.
THMM2	24632.4000	Z99922	171.107000	THMM2IC	0.
TICRL1	54.4810000	Z99959	0.00648499	TICRL1I	13.0000000
WMG2	374.077000	Z99979	6.3236E-05	WMG2IC	377.000000
WMM1	171.107000	Z99928	0.01276840	WMM1IC	0.
WMM2	171.107000	Z99923	0.01276840	WMM2IC	0.
Z99901	0.	Z99900	0.	Z99899	0.
Z99903	0.50609400	Z99902	4.1570E-04	VS1PUI	0.
Z99905	0.23668500	Z99904	-3.0047E-04	IDCR2IC	0.
Z99909	0.23668500	Z99908	-3.0047E-04	IDCR1IC	0.
Z99914	0.29332400	Z99913	-0.02582970	U2IC	0.99000000
Z99917	0.29332400	Z99916	-0.02582970	U1IC	0.99000000
Z99919	1.40698000	Z99918	0.00965595	EAFM2IC	1.00000000
Z99921	1.40698000	Z99920	0.00965595	EAFM1IC	1.00000000
Z99933	0.39940100	Z99932	-6.6878E-05	XMV1I	0.31609000
Z99935	7620.79000	Z99934	-0.24414100	NGGL1I	7193.84000
Z99937	94.6835000	Z99936	-0.02441410	PS3WC1I	68.0631000
Z99939	-3.3439E-05	Z99938	-1.5869E-05	EMFFB1I	0.
Z99941	54.5261000	Z99940	-0.01026270	ALPHA1I	40.9791000
Z99944	-345.138000	Z99943	-1.1160E-04	TGLAG1I	-345.140000
Z99948	-0.65392500	Z99947	5.9287E-04	TABTR1I	0.
Z99952	494.585000	Z99951	-0.52897100	QMAPL1I	0.
Z99954	3599.98000	Z99953	0.	NPTL1I	3600.00000
Z99956	26.9439000	Z99955	-0.00359245	P54LL1I	21.7097000
Z99958	26.5456000	Z99957	-0.00367846	P54L1I	21.3889000
Z99964	1475.83000	Z99963	-0.03127510	T51PL1I	1416.04000
Z99967	2005.19000	Z99966	-0.07290180	T4PL1I	1875.14000
Z99973	-0.08812110	Z99972	0.00382487	NERR1I	0.
Z99981	0.12512000	Z99980	-6.6678E-05	TMECH2IC	0.
Z99986	1.00000000	Z99985	0.	FUEL2IC	0.
Z99988	1.27530000	Z99987	2.6107E-04	EAFG2IC	1.00000000
Z99990	1.39421000	Z99989	6.2704E-04	EAFG1IC	1.00000000

Algebraic Variables

ommon Block /ZZCOMU/

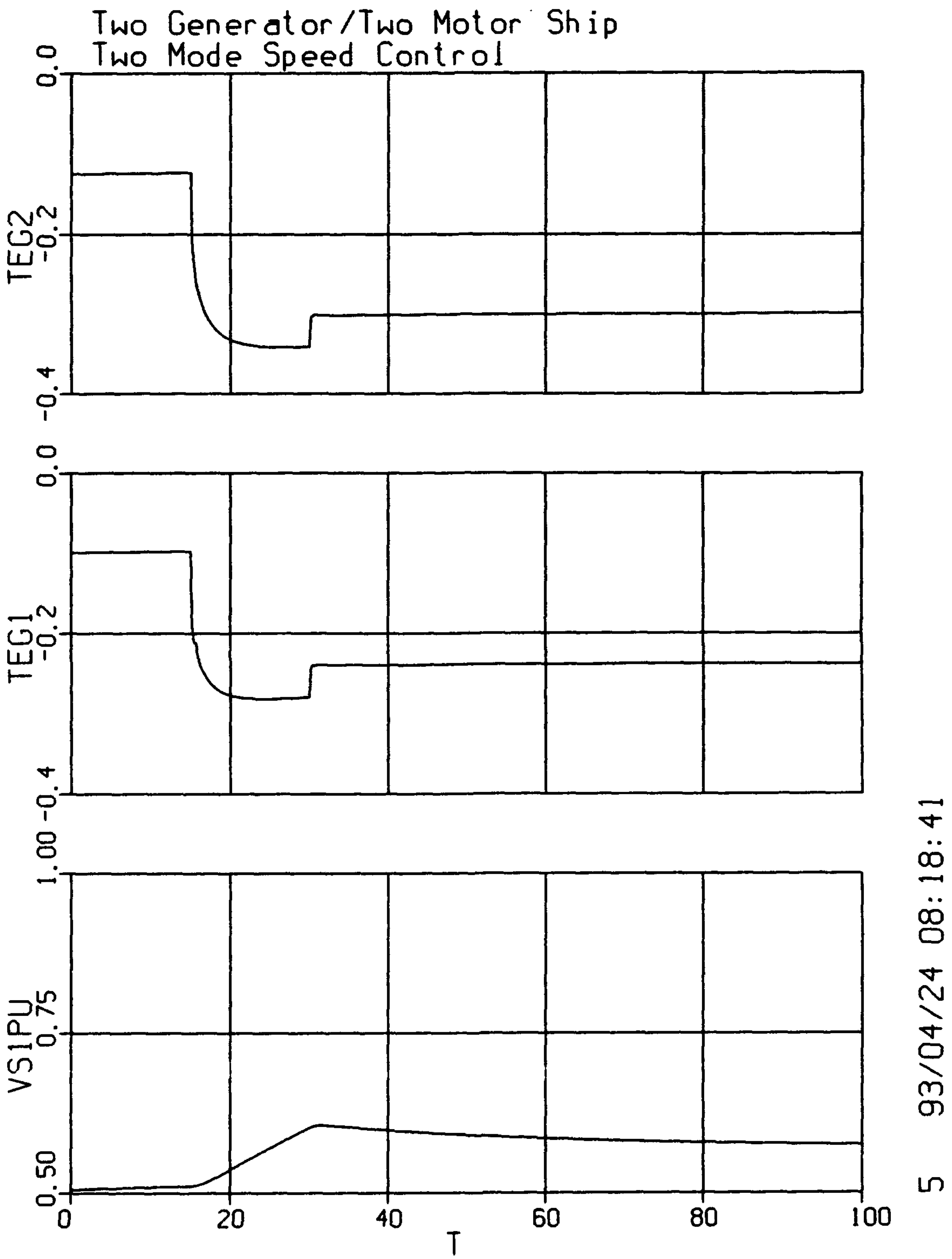
AFL1	0.17723600	AFRL1	0.17265700	ALPHA1	54.5261000
ALPHA1LL	13.0000000	ALPHA1UL	120.000000	ALPHAG1	54.0000000
ALPHAG2	20.7143000	ALPHAM1	18.4545000	ALPHAM2	18.4545000
ARLLG1I	0.31609000	BASEKWG1	16200.0000	BASEKWG2	2500.00000
BASEKWM1	14914.0000	BASEKWM2	14914.0000	BASENG1	3600.00000
BASENG2	900.000000	BASENM1	150.000000	BASENM2	150.000000
BASEQM1	949455.000	BASEQM2	949455.000	BASEVG1	4160.00000
BASEVG2	450.000000	BASEVM1	5000.00000	BASEVM2	5000.00000
BETAI1	2.20000000	BETAI2	2.20000000	BETAM1	2.20000000
BETAM2	2.20000000	BETAMINM1	1.57080000	BETAMINM2	1.57080000
BETAR1	1.27309000	BETAR2	1.27309000	CQLID1	2.8143E-05
CYL2	8.00000000	DELAY2	0.49478600	DELG1	0.11955700

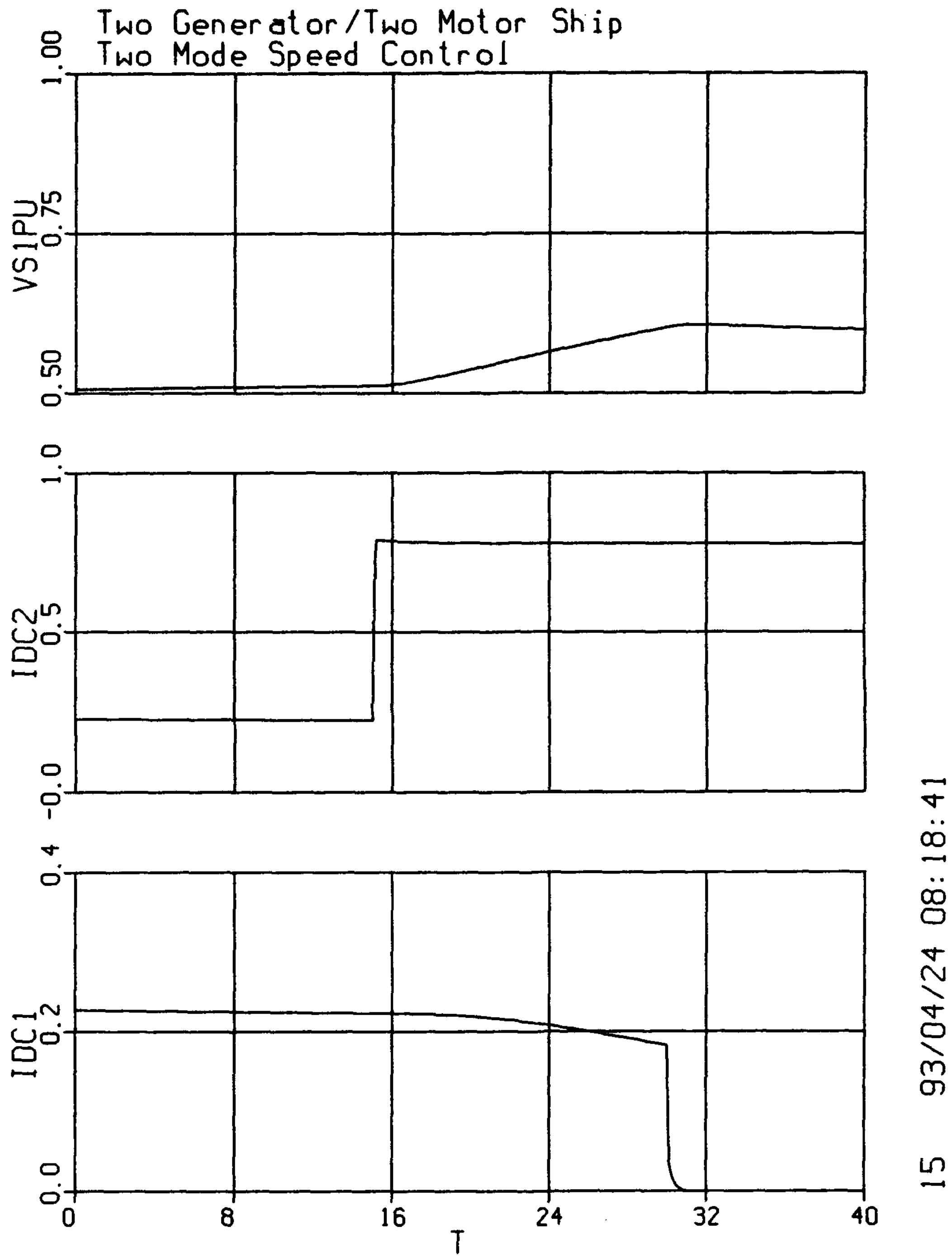
DELG2	0.10880500	DELI1	-0.19875100	DELI2	-0.19875100
DELM1	-0.16062700	DELM2	-0.16062700	DELR1	0.14401700
DELR2	0.14401700	DELTA2	1.00000000	DELV	1.0000E-04
DELVTQ1	0.	DELWF1	-0.60571300	DELWF1I	0.
DFL1	-0.75945400	DFRL1	-0.17252300	DN1	-0.00255082
DNGG1	7620.72000	DNPT1	-0.00255082	DNREF1	180.000000
DQ4S1	0.23181200	DQHR21	-0.68991700	DQPTR1	3975.34000
DRLLG1I	0.31609000	DRPMDT1	0.	DT4HS1	0.06348980
DT51HS1	0.05651400	DZ1	0.05000000	DZ2	0.05000000
E01I	0.	E211	-0.00424787	E221	-0.25487200
E231	-0.08495740	E51	8.45539000	E61	0.
E71	0.14404000	E81	0.	E91	0.45838300
EAFERRM1	9.6560E-06	EAFERRM2	9.6560E-06	EAFG1	1.39421000
EAFG1D	6.2704E-04	EAFG2	1.27530000	EAFG2D	2.6107E-04
EAFM1	1.40698000	EAFM1D	0.00965595	EAFM1MAX	3.00000000
EAFM1MIN	0.	EAFM2	1.40698000	EAFM2D	0.00965595
EAFM2MAX	3.00000000	EAFM2MIN	0.	EAFMAXG1	3.00000000
EAFMAXG2	3.00000000	EAFMING1	0.	EAFMING2	0.
EAFSM1	1.40699000	EAFSM2	1.40699000	EDPPG1D	-4.0735E-05
EDPPG2D	-3.7487E-05	EDPPM1D	1.1096E-04	EDPPM2D	1.1096E-04
EI1	0.46625000	EI2	0.46625000	EISM1	1.00000000
EISM2	1.00000000	EMFFB1	-3.3439E-05	EMFSAT1	-3.5977E-06
ENGG1	-3.5977E-06	ENPT1	7.19995000	ENPT1I	7.20000000
EPM1	1.28501000	EPM2	1.28501000	EQPG1D	-1.0709E-04
EQPG2D	5.5553E-05	EQPM1D	-2.4433E-04	EQPM2D	-2.4433E-04
EQPPG1D	-9.3806E-05	EQPPG2D	3.0887E-05	EQPPM1D	-2.4439E-04
EQPPM2D	-2.4439E-04	ER1	0.94481700	ER2	0.94481700
ERRBOUND	1.0000E-04	ERX1	-3.5977E-06	FARG0	0
FARG1	1	FARG2	2	FARG3	3
FARGS0	0	FARGS1	1	FARGS2	2
FARGS3	3	FUEL2	0.19580600	FUEL2MAX	1.00000000
FUEL2MIN	0.	FUELAG2	0.05038960	G11	0.22000000
G31	0.50000000	G51	0.50000000	GBETAR1	30.0000000
GBETAR2	30.0000000	GEAFG1	100.000000	GEAFG2	100.000000
GEAFM1	100.000000	GEAFM2	100.000000	GLARGE1	50.0000000
GLARGE2	50.0000000	GM1	1.50000000	GM2	1.50000000
GSMALL1	5.00000000	GSMALL2	5.00000000	GSPEED1	5.00000000
GSPEED2	5.00000000	HG1	0.92400000	HG2	1.91000000
HHPS	0.51678100	HM1	1.28978000	HM2	1.28978000
HP1	2475.06000	HP1B	25000.0000	HP1D	2475.06000
HP1I	0.	HP1ORD	0.	HP1ORDI	0.
HPT1ORD	2475.06000	IAJXQM1	0.28949400	IAJXQM2	0.28949400
IAM1	0.25021100	IAM2	0.25021100	ICLIM1	70.0000000
ICNTRL1	-0.08812110	ICNTRL1I	0.	ID1GR	1.00000000
IDBM1	0.	IDBM2	0.	IDC1D	0.00218158
IDC2D	0.00218158	IDCBG2	0.32394500	IDCOM1	0.23668500
IDCOM2	0.23668500	IDCR1	0.23668500	IDCR1D	-3.0047E-04
IDCR1DMAX	5.00000000	IDCR1DMIN	-5.00000000	IDCR1MAX	0.80000000
IDCR1MIN	0.	IDCR2	0.23668500	IDCR2D	-3.0047E-04
IDCR2DMAX	5.00000000	IDCR2DMIN	-5.00000000	IDCR2MAX	0.80000000
IDCR2MIN	0.	IDG1	0.22926900	IDG1IC	0.
IDG1M1	0.29932500	IDG2	0.17392700	IDG2ERR	0.
IDG2IC	0.	IDG2M1	0.32394500	IDI1	0.20229500
IDI2	0.20229500	IDL2	0.14486000	IDM1	0.20229500
IDM1IC	0.	IDM2	0.20229500	IDM2IC	0.

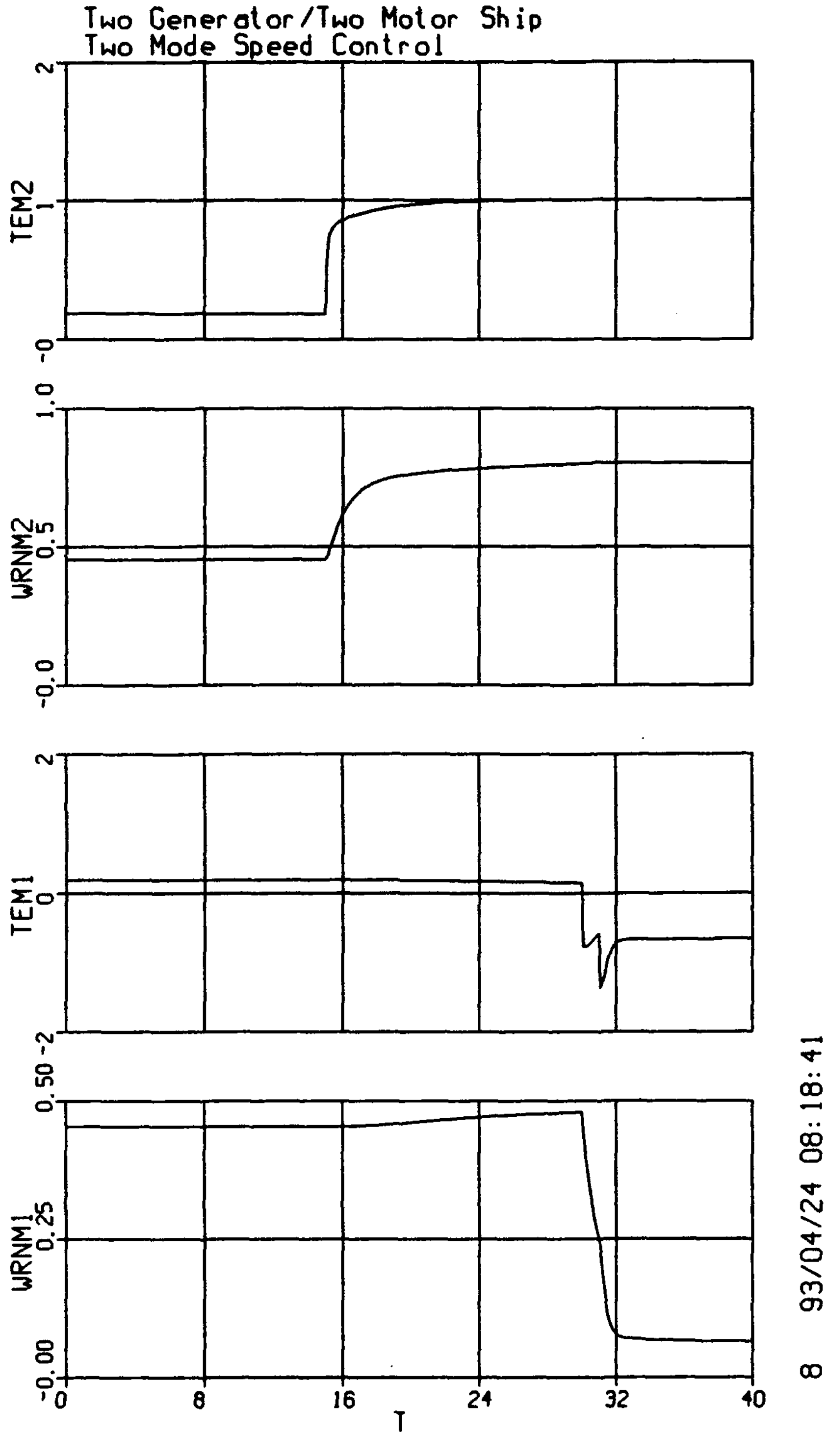
IDR1	0.23920500	IDR2	0.23920500	IDXM1	0.12198400
IDXM2	0.12198400	IERR1	0.00976887	IERR1IC	0.
IERR2	0.00976887	IERR2IC	0.	IGG1	566.778000
IITID1	580.484000	IQBM1	0.	IQBM2	0.
IQCBG2	0.19968600	IQG1	0.07243820	IQG1IC	0.
IQG1M1	0.09457250	IQG2	0.10721200	IQG2ERR	0.
IQG2IC	0.	IQG2M1	0.19968600	IQI1	-0.14724900
IQI2	-0.14724900	IQL2	0.14747300	IQM1	-0.14724900
IQM1IC	0.	IQM2	-0.14724900	IQM2IC	0.
IQR1	0.07339300	IQR2	0.07339300	JJG	16505.0000
JJPROP	1.3130E+06	JJPS	1.4790E+06	JJPT1	2171.50000
JJSHFT	166000.000	K00RES	0.	K01RES	0.20233900
K02RES	-0.05737380	K03RES	0.96980600	K04RES	-0.23175100
K05RES	8.65721000	K06RES	-5.19908000	K07RES	-23.5963000
K08RES	15.9458000	K09RES	20.3595000	K10RES	-15.1637000
KALARM1	0	KBRAKE1	1.00000000	KBRAKE2	1.00000000
KC11	0.50000000	KDFRQ	1.57080000	KGC	32.1740000
KGOV2	0.20000000	KHOLDPI1	1.00000000	KI	307.240000
KIG1M1	1.30556000	KIG2M1	1.86253000	KKWG1M1	1.08623000
KKWG2M1	0.16762800	KPNGG1	0.01017600	KQHP	5252.10000
KRAT1	0.16000000	KRATE1	10.0000000	KSHTDN1	0
KTBL1	0	KTURBO2	0.50000000	KVG1M1	0.83200000
KVG2M1	0.09000000	KVSHIP	0.00754970	KZG1M1	0.63727300
KZG2M1	0.04832140	LBRAKE1	F	LBRAKE2	F
LCBG2	T	LDOPLR	F	LFWD1	T
LFWD2	T	LHEADR	F	LHOLD1PI	F
LNGG1A	F	LPWRD1	F	LSEA	F
LT541A	F	MAXIT	10.0000000	MFKAC1	0.58200000
MFKFR1	0.17259000	MFKMV1	23.0000000	MFKN1	4.6080E-08
MFW1	159.400000		2091.30000		13659.6000
N1	3599.98000	N1I	3600.00000	N2	893.042000
NERR1	0.02294920	NGB	3600.00000	NGG1B	9827.00000
NGGL1	7620.79000	NMAX2	950.000000	NMIN2	400.000000
NP1PU	0.47042900	NP1PUI	5.3832E-06	NP1RPM	68.0797000
NP1RPMI	7.7905E-04	NP2PU	0.47042900	NP2PUI	5.3832E-06
NP2RMPI	7.7905E-04	NP2RPM	68.0797000	NPRPMB	144.719000
NPRPSB	2.41200000	NPT1B	3600.00000	NPT1ORD	3600.00000
NPT1ORDI	3600.00000	NPT1R	3600.00000	NPT1RI	3600.00000
NPTL1	3599.98000	NPTQ1	158.067000	NPTQ1I	158.068000
NPTR1	3599.98000	NPTR1I	3600.00000	NREF1	3672.00000
NSET2	900.000000	P1	0.16000000	P2	14.6960000
P2T21	5.50753000	P541	26.5455000	P541I	21.3889000
P54L1	26.5456000	P54LL1	26.9439000	P54Q1	1.83342000
P54Q1I	1.47725000	P54R21	26.5450000	P54R21I	21.3889000
PAMB	14.6960000	PCNTRL1	0.01147460	PCNTRL1I	0.
PCTID1	0.01000000	PHIPM1	2.20000000	PHIPM2	2.20000000
PHISM1	0.20000000	PHISM2	0.20000000	PNGG1	77.5494000
PNGGR1	77.5494000	PNGGR1I	73.2049000	PS31	94.6826000
PS31I	68.0631000	PS3R21	94.6826000	PS3R21I	68.0631000
PS3WC1	94.6835000	PWRD1	9.90022000	PWRD1I	0.
Q1	0.12000000	Q41	7320.23000	Q4R21	7320.23000
QCAL1	2723.95000	QCAL1I	0.	QGB	36520.0000
QH1	-0.45810500	QLID1	364.725000	QLID1I	364.730000
QMAP1	494.570000	QMAP1I	0.	QMAPL1	494.585000
QP1	234474.000	QP1F	6194.13000	QP1FI	92443.6000

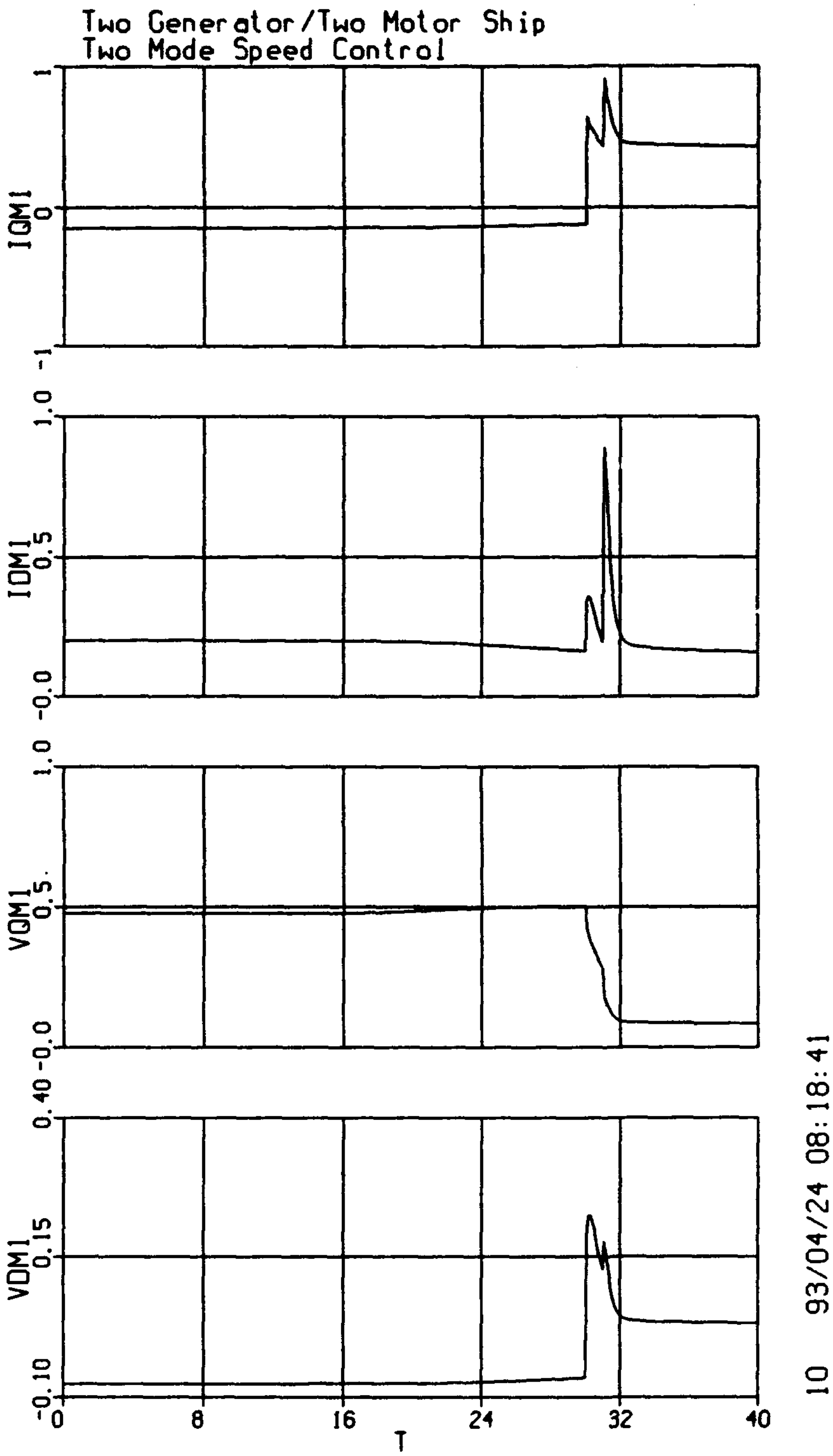
QP1I	-0.23332300	QP1PU	0.18923400	QP1PUI	-1.8831E-07
QP2	234474.000	QP2F	6194.13000	QP2FI	92443.6000
QP2I	-0.23332300	QP2PU	0.18923400	QP2PUI	-1.8831E-07
QPBASE	1.2391E+06	QPSBAF	92466.4000	QPT1	3975.49000
QPT1B	36473.0000	QPT1I	364.730000	QPT1PU	0.10885800
QREF1	45000.0000	RDC1	0.02000000	RDC2	0.02000000
RS1PU0	0.09625660	RS1PU1	-5.8911E-04	RS1PU2	0.09581350
RS1PU3	0.10240200	RS1PU	0.29388300	RS1PUI0	0.
RS1PUI1	0.	RS1PUI2	0.	RS1PUI3	0.
RS1PUI	0.	SEAFRQ	1.04720000	SEATIME	0.
SNEGVL1	0.	SPDERR1IC	0.	SPDERR2	6.95807000
SPDERR2IC	0.	SPDREF1	0.50000000	SPDREF2	0.50000000
SPEEDERR1	0.04613510	SPEEDERR2	0.04613510	SQRTH2	1.00000000
SWITCHVAR1	0.02903650	SWITCHVAR2	0.02903650	T0SEA	0.
T2	518.700000	T41	2004.96000	T4P1	2004.90000
T4PL1	2005.19000	T4R21	2004.90000	T4U1	-3.64363000
T511	1475.59000	T51P1	1475.53000	T51PL1	1475.83000
T51Q1	1.00004000	T51R21	1475.53000	T51U1	-3.62814000
T541	966.618000	TABTR11	0.54461100	TALPHA1(32)	999.900000
Z99976(16)	108.000000	Z99977(16)	999.900000	TAMB	59.0000000
TAUBETAR1	0.01000000	TAUBETAR2	0.01000000	TAUEAFG1	0.10000000
TAUEAFG2	0.10000000	TAUEAFM1	0.10000000	TAUEAFM2	0.10000000
TAUFAST1	0.10000000	TAUFAST2	0.10000000	TAUGOV2	2.00000000
TAUSLOW1	20.0000000	TAUSLOW2	20.0000000	TAUSPEED1	20.0000000
TAUSPEED2	20.0000000	TC11	3.00000000	TDOPG1	3.19000000
TDOPG2	3.79000000	TDOPM1	2.10000000	TDOPM2	2.10000000
TDOPPG1	0.04000000	TDOPPG2	0.38000000	TDOPPM1	0.03900000
TDOPPM2	0.03900000	TDT541(48)	99999.0000	Z99968(36)	68.3000000
Z99969(12)	99999.0000	TEG1	-0.09887520	TEG1IC	0.
TEG2	-0.12512000	TEM1	0.18932100	TEM2	0.18932100
TESM1	3610.92000	TESM1I	0.	TGLAG1	7.19996000
THDOT21	-0.00996538	THET2N	1.00000000	THETA2	1.00000000
THRESHOLD1	0.10000000	THRESHOLD2	0.10000000	THTA2V	1.00000000
TIC1	54.4816000	TIC1LL	13.0000000	TIC1UL	113.500000
TICMD1	54.4816000	TICMD1I	13.0000000	TICN1	-0.07664650
TICN1I	0.	TICRL1LL	-89.0000000	TICRL1UL	22.5000000
TICS1	54.5570000	TICS1I	13.0000000	TMAP(116)	950.000000
Z99997(96)	0.92280000	Z99998(20)	950.000000	TMG2	0.12512000
TMM1	-0.18923400	TMM2	-0.18923400	TORQ2	0.12508700
TP1PU	0.17447200	TP1PUI	0.	TP2PU	0.17447200
TP2PUI	0.	TQOPPG1	0.09000000	TQOPPG2	0.19000000
TQOPPM1	0.19300000	TQOPPM2	0.19300000	TSEA	6.00000000
TSTOP	160.000000	TURBOLAG2	0.44439700	TUT4H1	0.25220100
TUT51H1	0.10368500	TVSOREF	696.262000	U1	0.29332400
U1D	-0.02582970	U2	0.29332400	U2D	-0.02582970
UMAX1	0.99000000	UMAX2	0.99000000	UMIN1	0.
UMIN2	0.	VDBIC	0.	VDBUS	0.12826000
VDCBG2	0.12826000	VDERR	0.	VDG1	0.11880200
VDG2	0.10829200	VDI1	-0.09205850	VDI2	-0.09205850
VDM1	-0.07733350	VDM2	-0.07733350	VDR1	0.13560000
VDR2	0.13560000	VERRG1	0.01394270	VERRG2	0.01275330
VI1	-0.45383500	VI2	-0.45383500	VN1	7.34400000
VNSF1	500.000000	VQ1	9.00000000	VQBIC	1.00000000
VQBUS	0.95895700	VQCBG2	0.95895700	VQERR	0.
VQG1	0.98894700	VQG2	0.99134900	VQI1	0.45707100

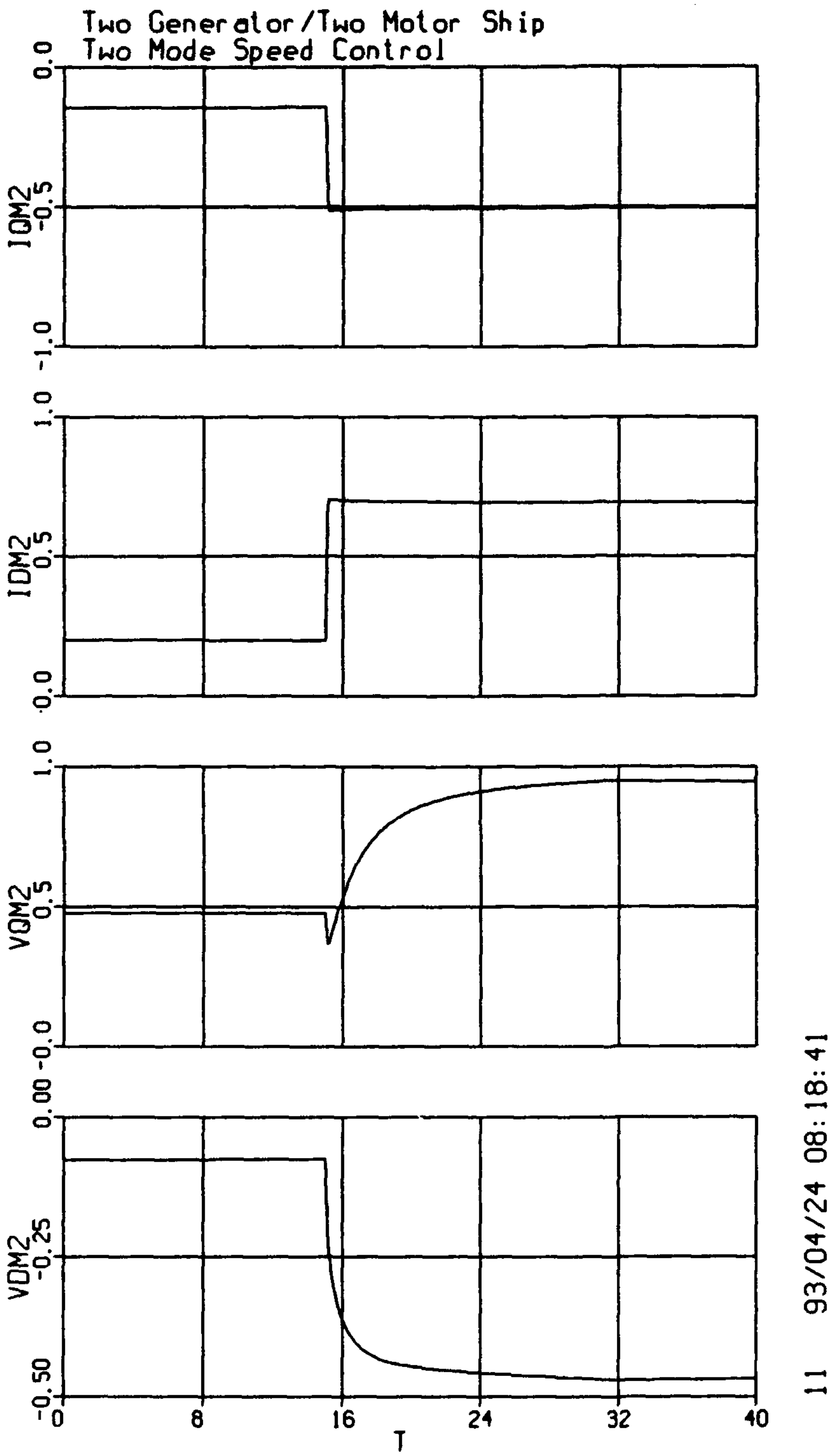
VQI2	0.45707100	VQM1	0.47730000	VQM2	0.47730000
VQR1	0.93503600	VQR2	0.93503600	VQSF1	5000.00000
VR1	0.45838300	VR2	0.45838300	VRATE1	0.
VRSF1	360.000000	VS1PU0	1.0000E-05	VS1PU10	0.00110232
VS1PU10I	0.	VS1PU2	0.25613100	VS1PU2I	0.
VS1PU3	0.12962600	VS1PU3I	0.	VS1PU4	0.06560300
VS1PU4I	0.	VS1PU5	0.03320130	VS1PU5I	0.
VS1PU6	0.01680290	VS1PU6I	0.	VS1PU7	0.00850387
VS1PU7I	0.	VS1PU8	0.00430375	VS1PU8I	0.
VS1PU9	0.00217810	VS1PU9I	0.	VS1PU	0.50609400
VT12	0.93604900	VTG1	0.99605700	VTG2	0.99724700
VTM1	0.48352500	VTM2	0.48352500	VTOP1	0.
VTREFG1	1.01000000	VTREFG2	1.01000000	VTRQGS1	0.
W41	57.3892000	W4R21	57.3892000	W541	64.1990000
W54R21	64.1990000	WAVE	4.00000000	WEFSEA	1.04720000
WESEA	0.	WESEAMG	0.	WESMAX	0.10000000
WFAC1	4302.86000	WFSR21	3173.84000	WFUEL1	3173.23000
WFUEL1I	2185.21000	WMG1	376.998000	WMG2D	6.3236E-05
WMM1D	0.01276840	WMM2D	0.01276840	WO	377.000000
WRN1ORD	1.00000000	WRN1ORDIC	1.00000000	WRNG1	0.99999400
WRNG1IC	1.00000000	WRNG2	0.99224700	WRNM1	0.45386500
WRNM2	0.45386500	XDC1	1.68000000	XDC2	1.68000000
XDG1	1.77000000	XDG2	1.63000000	XDM1	1.76000000
XDM2	1.76000000	XDMXQM1	0.60300000	XDMXQM2	0.60300000
XDPG1	0.18000000	XDPG2	0.25000000	XDPM1	0.60800000
XDPM2	0.60800000	XDPPG1	0.15000000	XDPPG2	0.18000000
XDPPM1	0.54200000	XDPPM2	0.54200000	XG1	0.10000000
XG2	0.10000000	XK3L1	2.20000000	XL1	0.10000000
XLG1	0.13000000	XLG2	0.07500000	XLM1	0.33700000
XLM2	0.33700000	XM1	0.10000000	XMV1	0.39936800
XQG1	1.64000000	XQG2	1.01000000	XQM1	1.15700000
XQM2	1.15700000	XQPPG1	0.15000000	XQPPG2	0.28000000
XQPPM1	0.49400000	XQPPM2	0.49400000	XVS0REF	207.220000
Z99871	0.32391200	Z99872	-0.97516100	Z99873	0.32394600
Z99874	0.32391200	Z99875	0.32392900	Z99877	1
Z99878	0.19968600	Z99879	-1.50261000	Z99880	0.19953500
Z99881	0.19978700	Z99882	0.19968800	Z99884	1
Z99885	0.95895700	Z99886	-1.09385000	Z99887	0.95890400
Z99888	0.95900500	Z99889	0.95901400	Z99891	1
Z99892	0.12826000	Z99893	-0.85598100	Z99894	0.12824300
Z99895	0.12828100	Z99896	0.12826000	Z99898	1
Z99906	0.02903650	Z99907	0.02903650	Z99910	0.02903650
Z99911	0.02903650	Z99945	7.19995000	Z99946	7.19996000
Z99949	0.54478900	Z99950	0.54461100	Z99960	47
Z99961	40	Z99962	49.2683000	Z99970	20
Z99971	54.5570000	Z99974	18	Z99975	13.0000000
Z99982	115	Z99983	99	Z99984	0.12508700
ZZSEED	55555555				


Two Generator/Two Motor Ship
Two Mode Speed Control
TEG2
0.0
-0.2
-0.4
TEG1
0.0
-0.2
-0.4
VS1PU
1.00
0.75
0.50
0
20
40
60
80
100
T
93/04/24 08:18:41
5

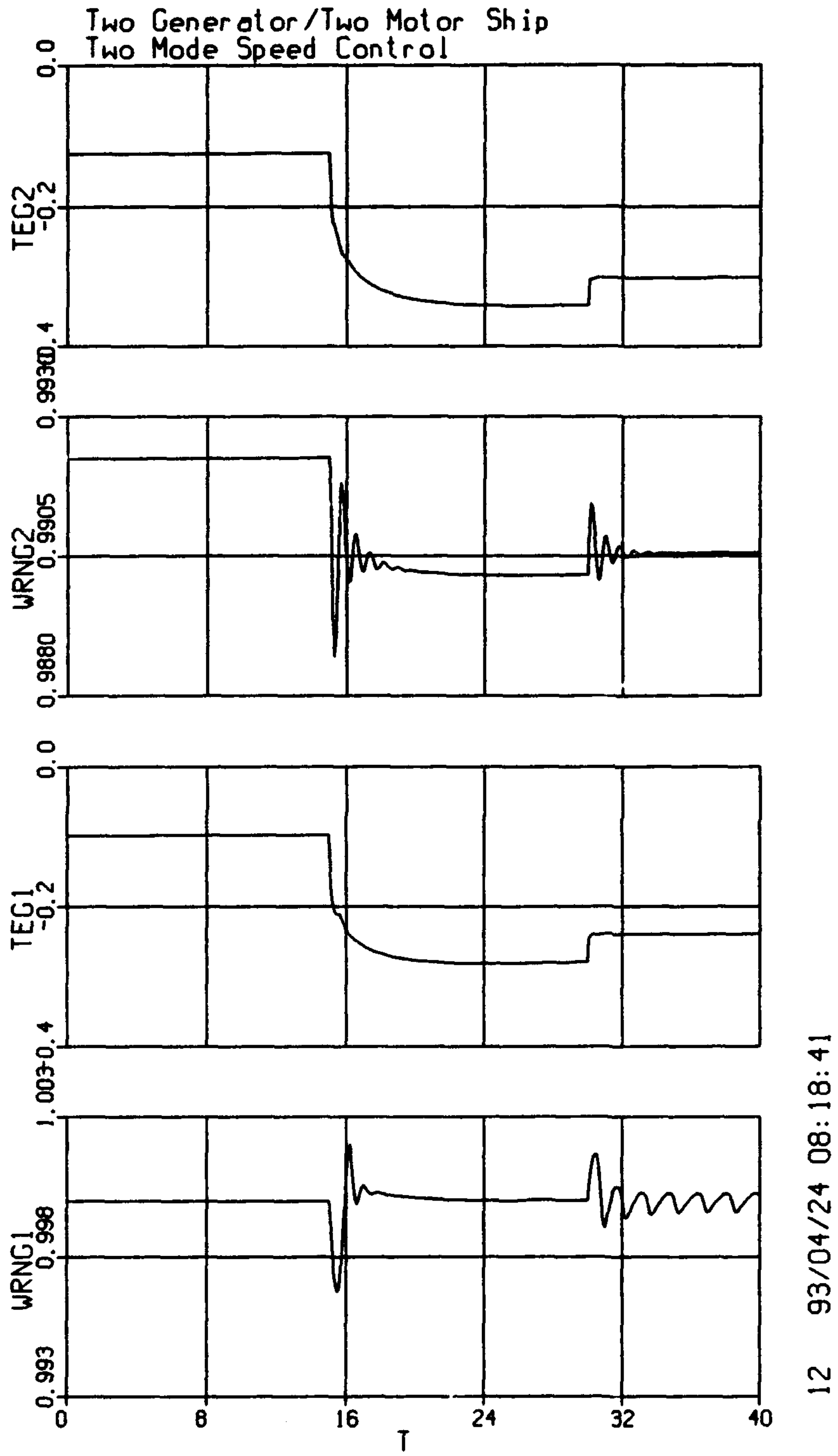

Two Generator/Two Motor Ship
Two Mode Speed Control
VS1PU
1.00
0.75
0.50
IDC2
1.0
0.5
-0.0
IDC1
0.4
0.2
0.0
0
8
16
24
32
40
T
93/04/24 08:18:41
15

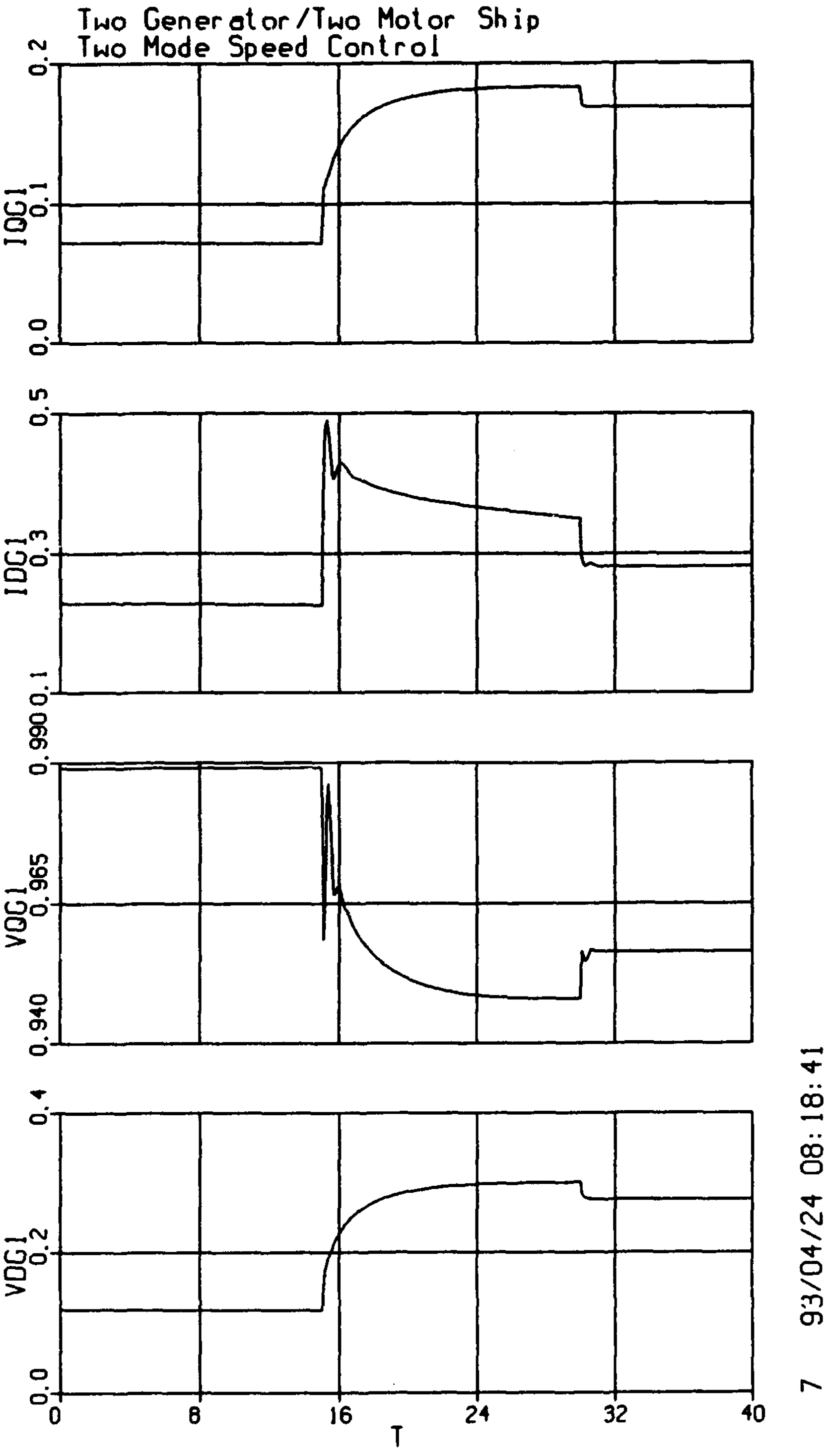

Two Generator/Two Motor Ship
Two Mode Speed Control
TEM2
WRNM2
TEM1
WRNM1
T
93/04/24 08:18:41
8


Two Generator/Two Motor Ship
Two Mode Speed Control
IQM1
IDM1
VQM1
VDM1
T
93/04/24 08:18:41
10

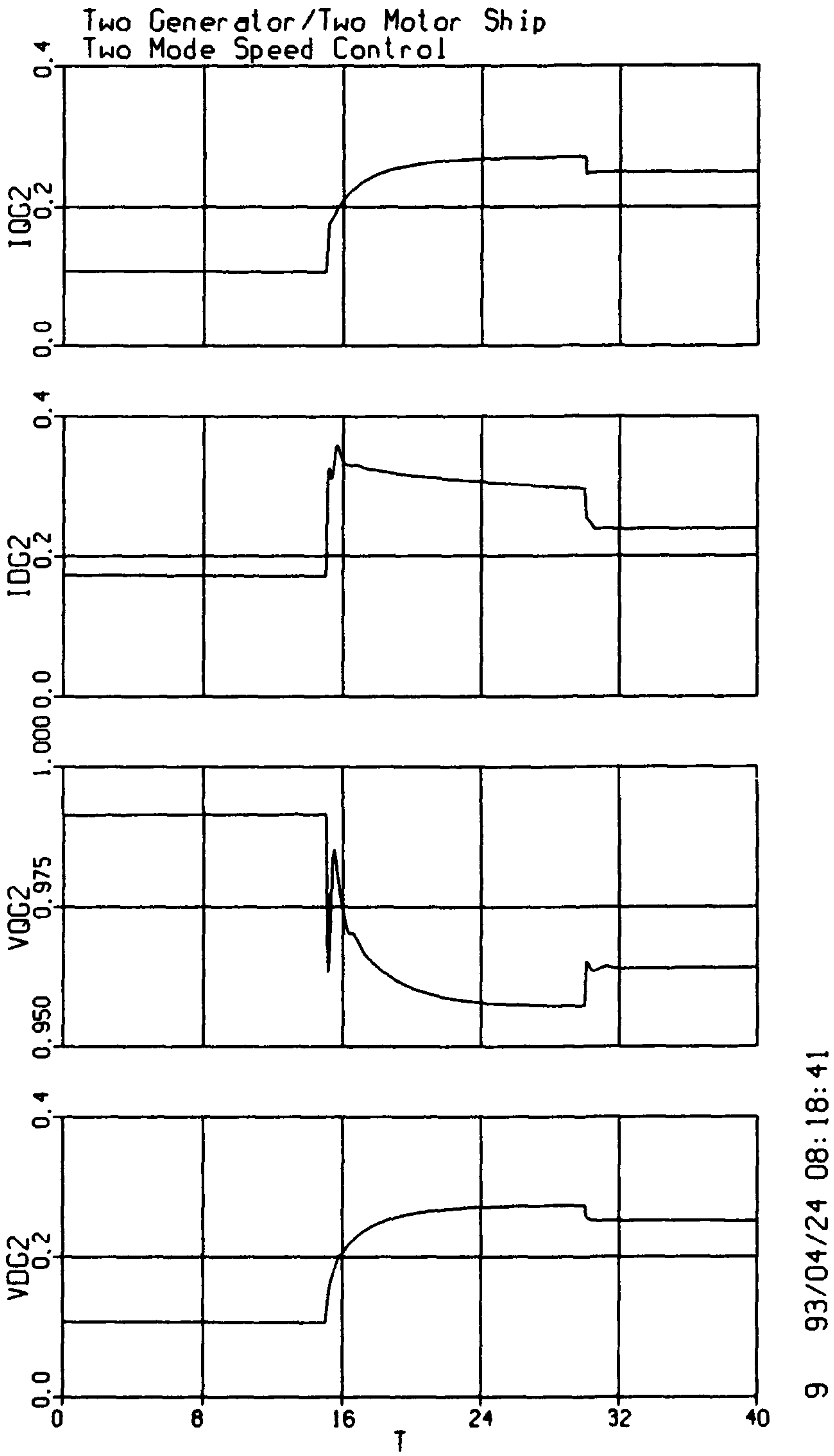


Two Generator/Two Motor Ship
Two Mode Speed Control
0.0
-0.5
IQM2
-1.0
1.0
0.5
IDM2
0.0
1.0
0.5
VQM2
-0.0
0.00
-0.25
VDM2
-0.50
0
8
16
24
32
40
T
11 93/04/24 08:18:41


Two Generator/Two Motor Ship
Two Mode Speed Control
TEG2
0.0
-0.2
-0.4
WRNG2
0.9930
0.9905
0.9880
TEG1
0.0
-0.2
-0.4
WRNG1
1.003
0.998
0.993
0
8
16
24
32
40
T
93/04/24 08:18:41
12



Two Generator/Two Motor Ship
Two Mode Speed Control
IQG1
0.0
0.1
0.2
IDG1
0.1
0.3
0.5
VQG1
0.940
0.965
0.990
VDG1
0.0
0.2
0.4
0
8
16
24
32
40
T
7 93/04/24 08:18:41


Two Generator/Two Motor Ship
Two Mode Speed Control
IQG2
IDG2
VQG2
VDG2
T
93/04/24 08:18:41
9

Appendix D: Simulation Output

This appendix contains an ACSL debug dump of all model values followed by graphical outputs of important variables of interest. The debug dump is rather lengthy, but this will allow re-creation of the simulation in the future if required. See appendix F for a dictionary of the variable names.

D.1 Acceleration From Rest

```
       T 150.000000       ZZTICG 0.                CINT 0.10000000
  ZZIERR     F            ZZNBLK        1        ZZICON        0
  ZZSTFL       T          ZZFRFL      F          ZZICFL     F
  ZZRNFL     F            ZZJEFL      F          ZZNIST       42
  ZZNAST        0           IALG        1          NSTP     100
    MAXT 0.10000000         MINT 1.0000E-08

 State Variables        Derivatives           Initial Conditions
  EDPPG1 0.20712500      Z99995 2.8048E-05     EDPPG1IC 0.
  EDPPG2 0.26969000      Z99992-2.4818E-05     EDPPG2IC 0.
  EDPPM1-0.42161800      Z99926-2.2142E-05     EDPPM1IC 0.
  ENPTL2 7.19999000      Z99940-4.7684E-05      ENPTL2I 7.20000000
   EQPG1 1.03756000      Z99994-2.1611E-05      EQPG1IC 1.00000000
   EQPG2 1.00525000      Z99991 7.1674E-06      EQPG2IC 1.00000000
   EQPM1 1.11792000      Z99925 8.2020E-07      EQPM1IC 1.00000000
  EQPPG1 1.01382000      Z99996 5.3622E-06     EQPPG1IC 1.00000000
  EQPPG2 0.99599300      Z99993-7.4970E-06     EQPPG2IC 1.00000000
  EQPPM1 1.06026000      Z99927-1.4624E-05     EQPPM1IC 1.00000000
    IDC1 0.97999000      Z99918 6.6976E-05       IDC1IC 0.
    NGG2 7939.00000      Z99963-8.2527E-04        NGG2I 7193.84000
    NPT2 3599.99000      Z99976-0.02691890        NPT2I 3600.00000
   THMG1 56018.5000      Z99978 373.192000       Z99977 0.
   THMG2 56552.3000      Z99929 376.999000       Z99928 0.
   THMM1 44224.0000      Z99923 366.055000      THMM1IC 0.
  TICRL2 64.6034000      Z99957 0.00938416      TICRL2I 13.0000000
    WMG1 373.192000      Z99979-7.4413E-04       WMG1IC 377.000000
    WMM1 366.055000      Z99924 0.01456500       WMM1IC 0.
  Z99913 0.              Z99912 0.               Z99911 0.
  Z99915 1.00474000      Z99914 7.6095E-05       VS1PUI 0.
  Z99917 1.00000000      Z99916 0.              IDCR1IC 0.
  Z99920 0.60061100      Z99919-0.03035660         U1IC 0.99000000
  Z99922 2.12437000      Z99921 0.              EAFM1IC 1.00000000
  Z99931 0.48354200      Z99930-6.6314E-07        XMV2I 0.31609000
  Z99933 7939.00000      Z99932 0.              NGGL2I 7193.84000
  Z99935 124.227000      Z99934 0.              PS3WC2I 68.0631000
```

Z99937	-3.3157E-07	Z99936	7.2369E-08	EMFFB2I	0.
Z99939	64.6195000	Z99938	0.	ALPHA2I	40.9791000
Z99942	-345.140000	Z99941	0.00237404	TGLAG2I	-345.140000
Z99946	-1.73586000	Z99945	-1.3908E-05	TABTR2I	0.
Z99950	1313.25000	Z99949	0.01220700	QMAPL2I	0.
Z99952	3599.99000	Z99951	-0.02882220	NPTL2I	3600.00000
Z99954	31.9862000	Z99953	-5.0712E-06	P54LL2I	21.7097000
Z99956	31.5135000	Z99955	0.	P54L2I	21.3889000
Z99962	1539.07000	Z99961	-3.9283E-04	T51PL2I	1416.04000
Z99965	2130.50000	Z99964	-0.01189530	T4PL2I	1875.14000
Z99971	-0.01978600	Z99970	0.00154622	NERR2I	0.
Z99981	0.36751700	Z99980	1.4538E-05	TMECH1IC	0.
Z99986	1.00000000	Z99985	0.	FUEL1IC	0.
Z99988	1.49561000	Z99987	0.00220656	EAFG2IC	1.00000000
Z99990	1.50550000	Z99989	-0.00187397	EAFG1IC	1.00000000

Algebraic Variables

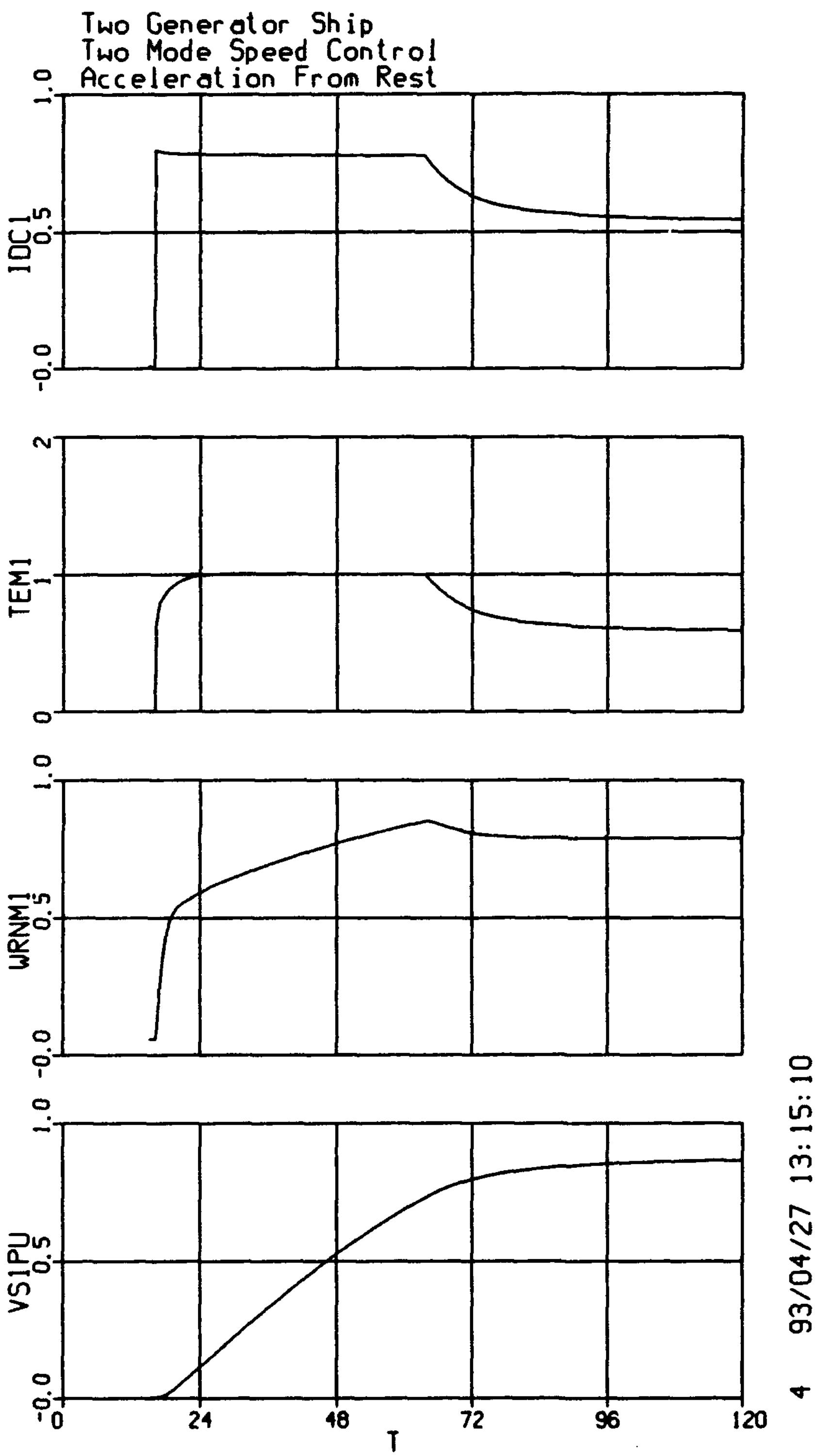
ommon Block /ZZCOMU/

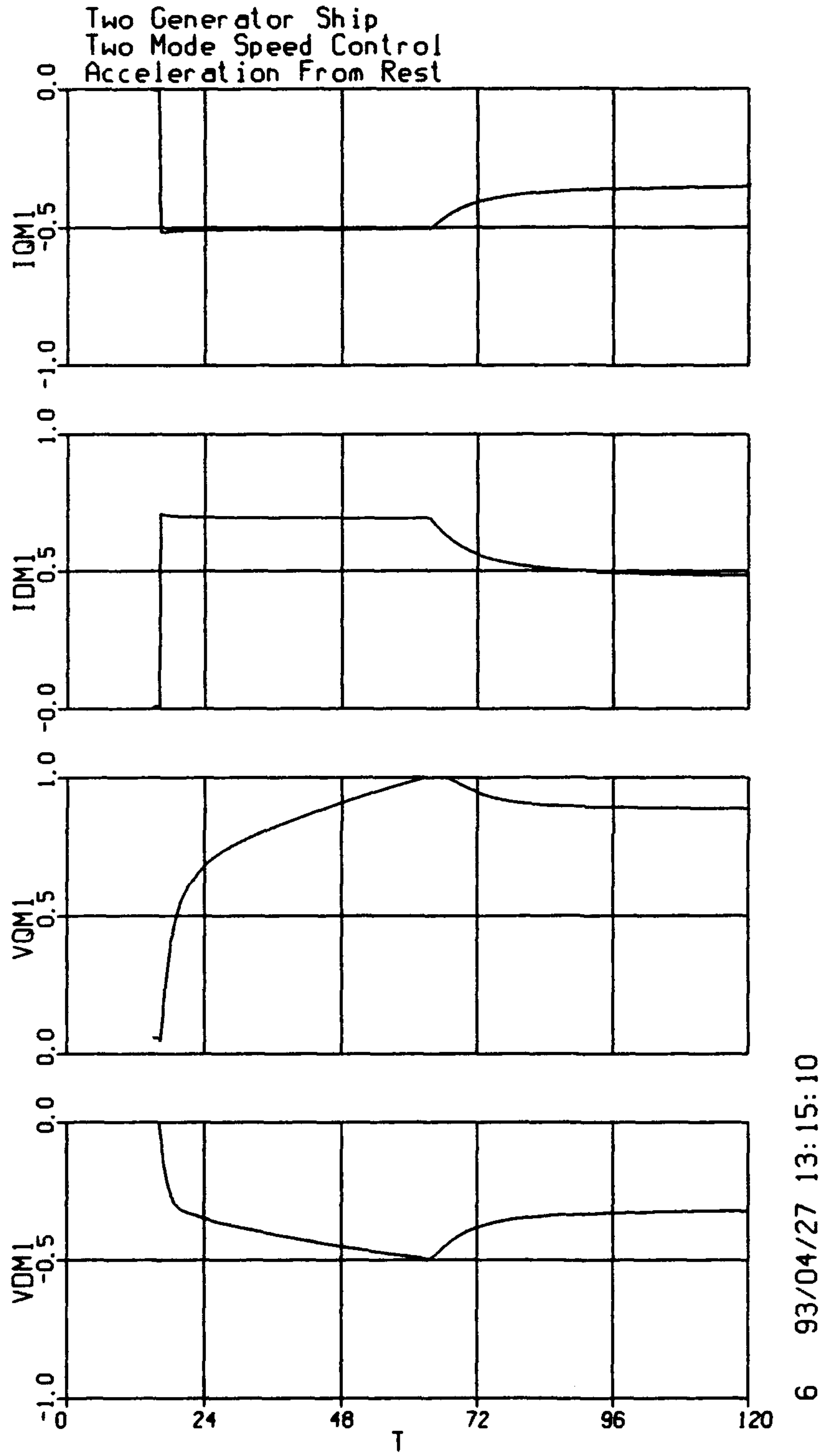
AFL2	0.16428700	AFRL2	0.17259100	ALPHA2	64.6195000
ALPHA2LL	13.0000000	ALPHA2UL	120.000000	ALPHAG1	20.7143000
ALPHAG2	54.0000000	ALPHAM1	18.4545000	ARLLG2I	0.31609000
BASEKWG1	2500.00000	BASEKWG2	16200.0000	BASEKWM1	14914.0000
BASENG1	900.000000	BASENG2	3600.00000	BASENM1	150.000000
BASEQM1	949455.000	BASEVG1	450.000000	BASEVG2	4160.00000
BASEVM1	5000.00000	BETAI1	2.20000000	BETAR1	0.92653200
CQLID2	2.8143E-05	CYL1	8.00000000	DELAY1	0.41613500
DELG1	0.29216700	DELG2	0.30293100	DELI1	-0.89761000
DELR1	0.42805300	DELTA2	1.00000000	DELV	1.0000E-04
DELVTQ2	0.	DELWF2	-0.03955080	DELWF2I	0.
DFL2	-0.77240300	DFRL2	-0.17258900	DN2	-0.02691890
DNGG2	7939.00000	DNPT2	-0.02691890	DNREF2	180.000000
DQ4S2	0.03920190	DQHR22	-0.04072430	DQPTR2	9984.12000
DRLLG2I	0.31609000	DRPMDT2	-3.5858E-05	DT4HS2	0.00812641
DT51HS2	5.5702E-04	E02I	0.	E212	-0.00151284
E222	-0.09077050	E232	-0.03025680	E52	7.55344000
E62	0.	E72	0.14412100	E82	0.
E92	0.50003600	EAFERRM1	0.	EAFG1	1.50550000
EAFG1D	-0.00187397	EAFG2	1.49561000	EAFG2D	0.00220656
EAFM1	2.12437000	EAFM1D	0.	EAFM1MAX	4.00000000
EAFM1MIN	0.	EAFMAXG1	3.00000000	EAFMAXG2	3.00000000
EAFMING1	0.	EAFMING2	0.	EAFSM1	2.12437000
EDPPG1D	2.8048E-05	EDPPG2D	-2.4818E-05	EDPPM1D	-2.2142E-05
EI1	0.91375200	EISM1	1.00000000	EMFFB2	-3.3157E-07
EMFSAT2	-2.5686E-08	ENGG2	-2.5686E-08	ENPT2	7.19999000
ENPT2I	7.20000000	EPM1	1.58679000	EQPG1D	-2.1611E-05
EQPG2D	7.1674E-06	EQPM1D	8.2020E-07	EQPPG1D	5.3622E-06
EQPPG2D	-7.4970E-06	EQPPM1D	-1.4624E-05	ER1	0.91505900
ERRBOUND	1.0000E-04	ERX2	-2.5686E-08	FARG0	0
FARG1	1	FARG2	2	FARG3	3
FARGS0	0	FARGS1	1	FARGS2	2
FARGS3	3	FUEL1	0.40711500	FUEL1MAX	1.00000000
FUEL1MIN	0.	FUELAG1	0.05050910	G12	0.22000000
G32	0.50000000	G52	0.50000000	GBETAR1	30.0000000
GEAFG1	100.000000	GEAFG2	100.000000	GEAFM1	100.000000

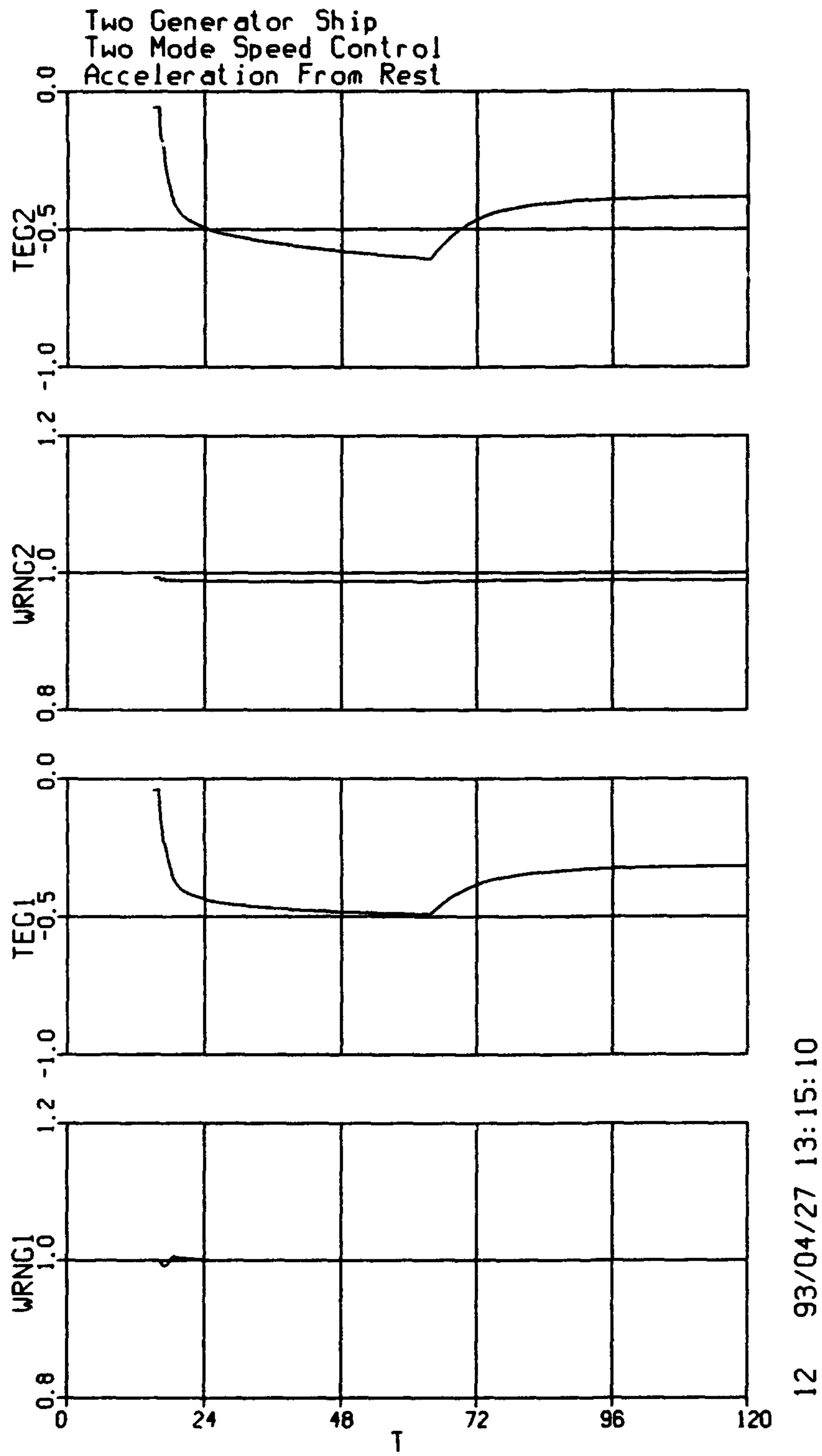
GSPEED1	100.000000	HG1	1.91000000	HG2	0.92400000
HHPS	0.51678100	HM1	1.28978000	HP2	6594.62000
HP2B	25000.0000	HP2D	6594.62000	HP2I	0.
HP2ORD	0.	HP2ORDI	0.	HPT2ORD	6594.62000
IAJXQM1	1.04928000	ICLIM2	70.0000000	ICNTRL2	-0.01978600
ICNTRL2I	0.	ID2GR	1.00000000	IDC1D	6.6976E-05
IDCR1	1.00000000	IDCR1D	10.0000000	IDCR1DMAX	10.0000000
IDCR1DMIN	-10.0000000	IDCR1MAX	1.00000000	IDCR1MIN	0.
IDG1	0.33911600	IDG1IC	0.	IDG2	0.30839800
IDG2ERR	0.	IDG2IC	0.	IDL2	0.17026800
IDM1	0.87365600	IDM1IC	0.	IDR1	0.86397900
IDSM1	0.89149500	IDXM1	0.53757100	IERR1	0.02001020
IERR1IC	0.	IGG2	566.778000	IITID2	580.484000
IQG1	0.28374100	IQG1IC	0.	IQG2	0.18099900
IQG2ERR	0.	IQG2IC	0.	IQL2	0.11576500
IQM1	-0.63593000	IQM1IC	0.	IQR1	0.64901600
JJG	16505.0000	JJPROP	1.3130E+06	JJPS	1.4790E+06
JJPT2	2171.50000	JJSHFT	166000.000	K00RES	0.
K01RES	0.20233900	K02RES	-0.05737380	K03RES	0.96980600
K04RES	-0.23175100	K05RES	8.65721000	K06RES	-5.19908000
K07RES	-23.5963000	K08RES	15.9458000	K09RES	20.3595000
K10RES	-15.1637000	KALARM2	0	KC12	0.50000000
KDFRQ	1.57080000	KGC	32.1740000	KGOV1	0.20000000
KHOLDPI2	1.00000000	KI	307.240000	KIG1M1	1.86253000
KIG2M1	1.30556000	KKWG1M1	0.16762800	KKWG2M1	1.08623000
KPNGG2	0.01017600	KQHP	5252.10000	KRAT2	0.16000000
KRATE2	10.0000000	KSHTDN2	0	KTBL2	0
KTURBO1	0.50000000	KVG1M1	0.09000000	KVG2M1	0.83200000
KVSHIP	0.00754970	KZG1M1	0.04832140	KZG2M1	0.63727300
LDOPLR	F	LFWD1	T	LHEADR	F
LHOLD2PI	F	LNGG2A	F	LPWRD2	F
LSEA	F	LT542A	F	MAXIT	10.0000000
MFKAC2	0.58200000	MFKFR2	0.17259000	MFKMV2	23.0000000
MFKN2	4.6080E-08	MFW2	159.400000		2091.30000
	13659.6000	N1	890.929000	N2	3599.99000
N2I	3600.00000	NERR2	0.00927734	NGB	3600.00000
NGG2B	9827.00000	NGGL2	7939.00000	NMAX1	950.000000
NMIN1	400.000000	NP1PU	1.00640000	NP1PUI	5.3832E-06
NP1RPM	145.645000	NP1RPMI	7.7905E-04	NP2PU	1.00640000
NP2PUI	5.3832E-06	NP2RMPI	7.7905E-04	NP2RPM	145.645000
NPRPMB	144.719000	NPRPSB	2.41200000	NPT2B	3600.00000
NPT2ORD	3600.00000	NPT2ORDI	3600.00000	NPT2R	3600.00000
NPT2RI	3600.00000	NPTL2	3599.99000	NPTQ2	158.068000
NPTQ2I	158.068000	NPTR2	3599.99000	NPTR2I	3600.00000
NREF2	3672.00000	NSET1	900.000000	P1	0.16000000
P2	14.6960000	P2T22	5.50753000	P542	31.5135000
P542I	21.3889000	P54L2	31.5135000	P54LL2	31.9862000
P54Q2	2.17652000	P54Q2I	1.47725000	P54R22	31.5135000
P54R22I	21.3889000	PAMB	14.6960000	PCNTRL2	0.00463867
PCNTRL2I	0.	PCTID2	0.01000000	PHISM1	0.20000000
PNGG2	80.7877000	PNGGR2	80.7877000	PNGGR2I	73.2049000
PS32	124.227000	PS32I	68.0631000	PS3R22	124.227000
PS3R22I	68.0631000	PS3WC2	124.227000	PWRD2	26.3785000
PWRD2I	0.	Q1	0.12000000	Q42	10277.3000
Q4R22	10277.3000	QCAL2	7232.78000	QCAL2I	0.

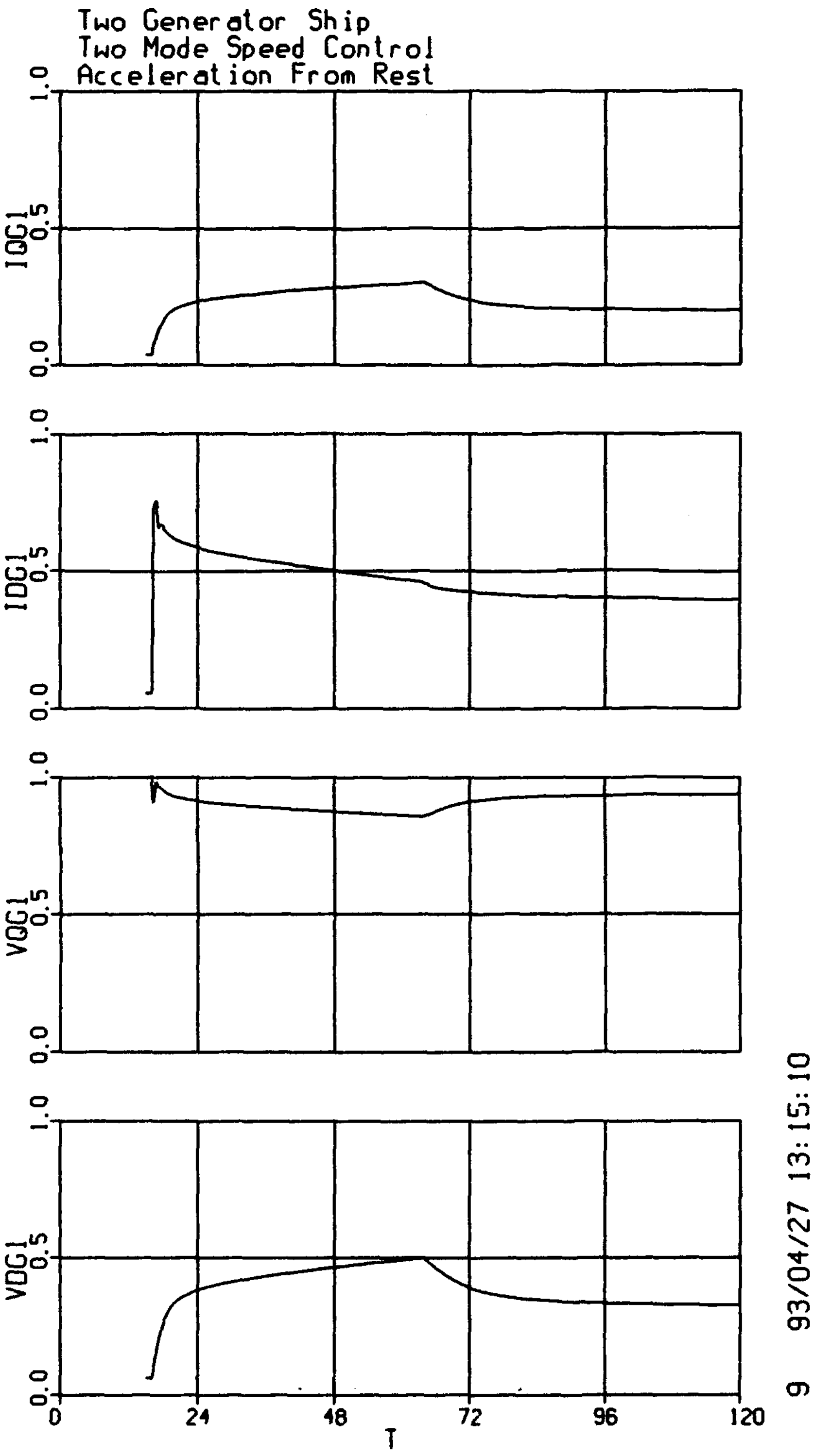
QGB	36520.0000	QH2	-0.00152240	QLID2	364.728000
QLID2I	364.730000	QMAP2	1313.25000	QMAP2I	0.
QMAPL2	1313.25000	QP1	1.2587E+06	QP1F	12771.9000
QP1FI	92443.6000	QP1I	-0.23332300	QP1PU	1.01583000
QP1PUI	-1.8831E-07	QP2	1.2587E+06	QP2F	12771.9000
QP2FI	92443.6000	QP2I	-0.23332300	QP2PU	1.01583000
QP2PUI	-1.8831E-07	QPBASE	1.2391E+06	QPSBAF	92466.4000
QPT2	9984.12000	QPT2B	36473.0000	QPT2I	364.730000
QPT2PU	0.27338800	QREF2	45000.0000	RDC1	0.02000000
RS1PU0	21.9066000	RS1PU1	-20.8741000	RS1PU2	0.68955800
RS1PU3	0.20329700	RS1PU	1.92537000	RS1PUI0	0.
RS1PUI1	0.	RS1PUI2	0.	RS1PUI3	0.
RS1PUI	0.	SEAFRQ	1.04720000	SEATIME	0.
SNEGVL2	0.	SPDERR1	9.07117000	SPDREF1	1.00000000
SPEEDERR1	0.02903100	SQRTH2	1.00000000	T0SEA	0.
T2	518.700000	T42	2130.46000	T4P2	2130.46000
T4PL2	2130.50000	T4R22	2130.46000	T4U2	-0.59452800
T512	1539.07000	T51P2	1539.07000	T51PL2	1539.07000
T51Q2	1.00000000	T51R22	1539.07000	T51U2	-0.04557140
T542	1026.56000	TABTR12	1.44656000	TALPHA2(32)	999.900000
Z99974(16)	108.000000	Z99975(16)	999.900000	TAMB	59.0000000
TAUBETAR1	0.01000000	TAUEAFG1	0.10000000	TAUEAFG2	0.10000000
TAUEAFM1	0.05000000	TAUGOV1	2.00000000	TAUSPEED1	0.10000000
TC12	3.00000000	TDOPG1	3.79000000	TDOPG2	3.19000000
TDOPM1	2.10000000	TDOPPG1	0.38000000	TDOPPG2	0.04000000
TDOPPM1	0.03900000	TDT542(48)	99999.0000	Z99966(36)	68.3000000
Z99967(12)	99999.0000	TEG1	-0.36752500	TEG2	-0.26344600
TEG2IC	0.	TEM1	1.01593000	TESM2	9621.03000
TESM2I	0.	TGLAG2	7.19988000	THDOT22	0.
THET2N	1.00000000	THETA2	1.00000000	THTA2V	1.00000000
TIC2	64.6044000	TIC2LL	13.0000000	TIC2UL	113.500000
TICMD2	64.6044000	TICMD2I	13.0000000	TICN2	-0.01514730
TICN2I	0.	TICRL2LL	-89.0000000	TICRL2UL	22.5000000
TICS2	64.6200000	TICS2I	13.0000000	TMAP(116)	950.000000
Z99997(96)	0.92280000	Z99998(20)	950.000000	TMG1	0.36751700
TMM1	-1.01583000	TMM2	-1.01583000	TORQ1	0.36752300
TP1PU	0.96772600	TP1PUI	0.	TP2PU	0.96772600
TP2PUI	0.	TQOPPG1	0.19000000	TQOPPG2	0.09000000
TQOPPM1	0.19300000	TSEA	6.00000000	TSTOP	150.000000
TURBOLAG1	0.36562600	TUT4H2	0.29891600	TUT51H2	0.12377200
TVS0REF	696.262000	U1	0.60061100	U1D	-0.03035660
UMAX1	0.99000000	UMIN1	0.	VDBIC	0.
VDBUS	0.31494000	VDERR	0.	VDG1	0.28657300
VDG2	0.29684000	VDM1	-0.71440700	VDR1	0.37984100
VERRG1	0.01505320	VERRG2	0.01495830	VI1	-0.88942200
VN2	7.34400000	VNSF2	500.000000	VQ2	9.00000000
VQBIC	1.00000000	VQBUS	0.91889700	VQERR	0.
VQG1	0.95278300	VQG2	0.94973400	VQM1	0.56970600
VQR1	0.83249900	VQSF2	5000.00000	VR1	0.90902200
VR2	0.50000000	VRATE2	0.	VRSF2	360.000000
VS1PU0	1.0000E-05	VS1PU10	1.04838000	VS1PU10I	0.
VS1PU2	1.00949000	VS1PU2I	0.	VS1PU3	1.01427000
VS1PU3I	0.	VS1PU4	1.01908000	VS1PU4I	0.
VS1PU5	1.02390000	VS1PU5I	0.	VS1PU6	1.02875000
VS1PU6I	0.	VS1PU7	1.03362000	VS1PU7I	0.

VS1PU8	1.03852000	VS1PU8I	0.	VS1PU9	1.04344000
VS1PU9I	0.	VS1PU	1.00474000	VT12	0.94355800
VTG1	0.99494700	VTG2	0.99504200	VTOP2	0.
VTREFG1	1.01000000	VTREFG2	1.01000000	VTRQGS2	0.
W42	73.1600000	W4R22	73.1600000	W542	81.8123000
W54R22	81.8123000	WAVE	4.00000000	WEFSEA	1.04720000
WESEA	0.	WESEAMG	0.	WESMAX	0.10000000
WFAC2	5787.87000	WFSR22	4364.46000	WFUEL2	4364.42000
WFUEL2I	2185.21000	WMG1D	-7.4413E-04	WMG2	376.999000
WMM1D	0.01456500	WO	377.000000	WRN2ORD	1.00000000
WRN2ORDIC	1.00000000	WRNG1	0.98989900	WRNG2	0.99999700
WRNG2IC	1.00000000	WRNM1	0.97096900	WRNM2	0.97096900
XDC1	1.68000000	XDG1	1.63000000	XDG2	1.77000000
XDM1	1.76000000	XDMXQM1	0.60300000	XDPG1	0.25000000
XDPG2	0.18000000	XDPM1	0.60800000	XDPPG1	0.18000000
XDPPG2	0.15000000	XDPPM1	0.54200000	XG1	0.10000000
XG2	0.10000000	XK3L2	2.20000000	XL1	0.10000000
XLG1	0.07500000	XLG2	0.13000000	XLM1	0.33700000
XMV2	0.48354200	XQG1	1.01000000	XQG2	1.64000000
XQM1	1.15700000	XQPPG1	0.28000000	XQPPG2	0.15000000
XQPPM1	0.49400000	XVS0REF	207.220000	Z99883	0.30836800
Z99884	0.	Z99885	0.30841400	Z99886	0.30836800
Z99887	0.30836800	Z99889	1	Z99890	0.18098100
Z99891	0.	Z99892	0.18101400	Z99893	0.18098100
Z99894	0.18099700	Z99896	1	Z99897	0.91889700
Z99898	-1.96239000	Z99899	0.91864100	Z99900	0.91902700
Z99901	0.91887100	Z99903	1	Z99904	0.31494000
Z99905	-2.66414000	Z99906	0.31488000	Z99907	0.31496200
Z99908	0.31494700	Z99910	1	Z99943	7.19999000
Z99944	7.19988000	Z99947	1.44656000	Z99948	1.44656000
Z99958	47	Z99959	40	Z99960	52.8073000
Z99968	22	Z99969	64.6200000	Z99972	18
Z99973	13.0000000	Z99982	115	Z99983	100
Z99984	0.36752300	ZZSEED	55555555		

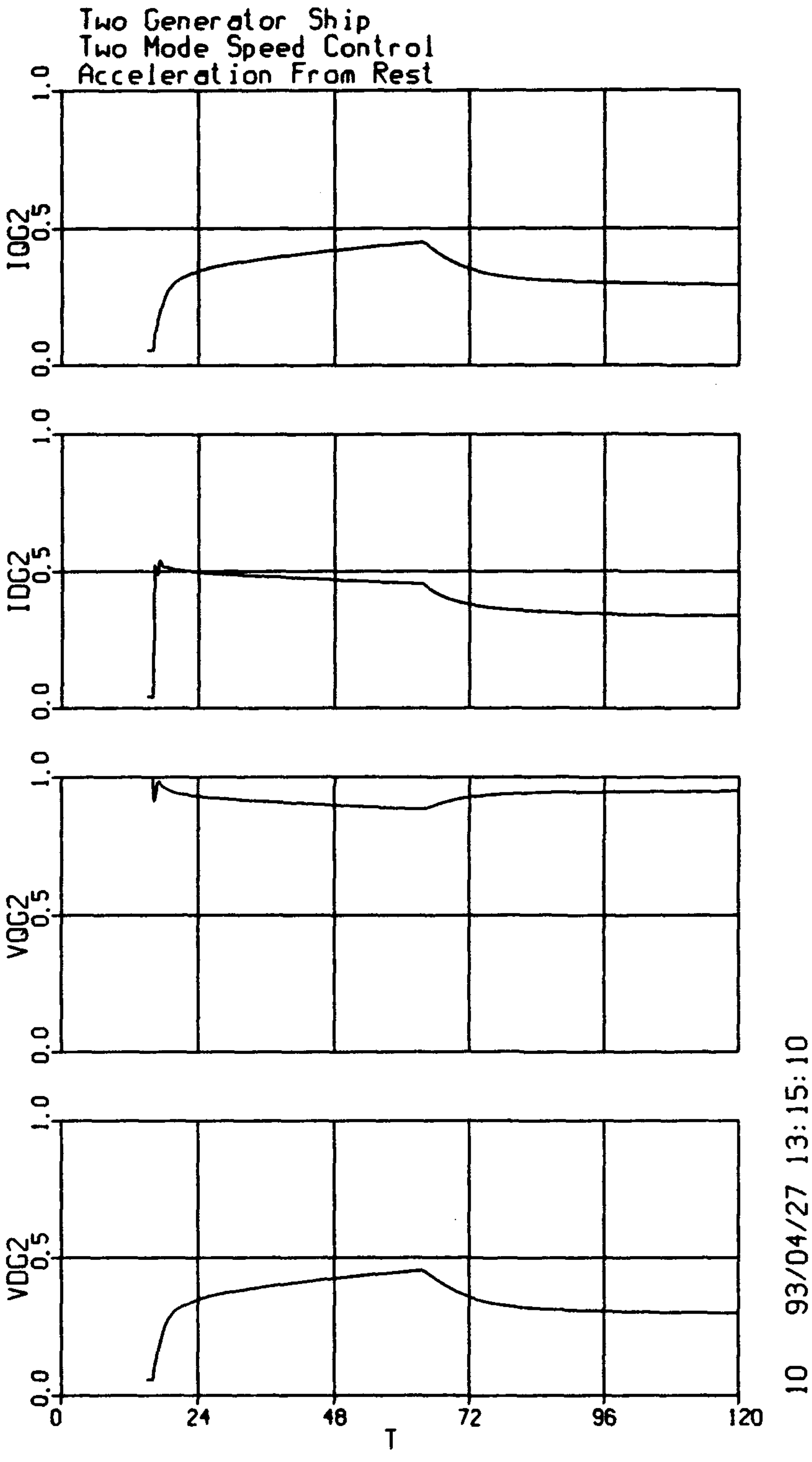

Two Generator Ship
Two Mode Speed Control
Acceleration From Rest
IDC1
TEM1
WRNM1
VS1PU
T
93/04/27 13:15:10
4


Two Generator Ship
Two Mode Speed Control
Acceleration From Rest
IQM1
IDM1
VQM1
VDM1
T
93/04/27 13:15:10
6


Two Generator Ship
Two Mode Speed Control
Acceleration From Rest
TEG2
WRNG2
TEG1
WRNG1
T
0.0
-0.5
-1.0
1.2
1.0
0.8
0
24
48
72
96
120
93/04/27 13:15:10
12



Two Generator Ship
Two Mode Speed Control
Acceleration From Rest
IQG1
IDG1
VQG1
VDG1
0.0
0.5
1.0
0
24
48
72
96
120
T
9 93/04/27 13:15:10


Two Generator Ship
Two Mode Speed Control
Acceleration From Rest
IQG2
IDG2
VQG2
VDG2
0.0
0.5
1.0
0
24
48
72
96
120
T
93/04/27 13:15:10
10

D.2 Single Mode Speed Control in Moderate Seas

System #2: moderate waves

T	150.000000	ZZTICG	0.	CINT	0.10000000
ZZIERR	F	ZZNBLK	1	ZZICON	0
ZZSTFL	T	ZZFRFL	F	ZZICFL	F
ZZRNFL	F	ZZJEFL	F	ZZNIST	40
ZZNAST	0	IALG	1	NSTP	10
MAXT	0.10000000	MINT	1.0000E-08		

State Variables		Derivatives		Initial Conditions	
EDPPG1	0.10393600	Z99995	0.01313510	EDPPG1IC	0.
EDPPG2	0.13385500	Z99992	0.01724740	EDPPG2IC	0.
EDPPM1	-0.24317800	Z99930	-0.05109890	EDPPM1IC	0.
ENPTL2	7.19951000	Z99942	4.0531E-04	ENPTL2I	7.20000000
EQPG1	1.05134000	Z99994	0.00710219	EQPG1IC	1.00000000
EQPG2	1.02220000	Z99991	0.00198796	EQPG2IC	1.00000000
EQPM1	0.99769300	Z99929	0.00350416	EQPM1IC	1.00000000
EQPPG1	1.03125000	Z99996	0.00520087	EQPPG1IC	1.00000000
EQPPG2	1.01603000	Z99993	0.00142611	EQPPG2IC	1.00000000
EQPPM1	0.96322100	Z99931	-0.00344501	EQPPM1IC	1.00000000
IDC1	0.58815000	Z99922	0.11471900	IDC1IC	0.
NGG2	7652.43000	Z99965	38.1411000	NGG2I	7193.84000
NPT2	3599.80000	Z99978	0.31122000	NPT2I	3600.00000
THMM1	37119.1000	Z99927	273.519000	THMM1IC	0.
TICRL2	55.8717000	Z99959	1.17374000	TICRL2I	13.0000000
WMG1	373.828000	Z99979	-0.06713930	WMG1IC	377.000000
WMM1	273.519000	Z99928	-1.64936000	WMM1IC	0.
Z99917	0.12000000	Z99916	1.8626E-08	Z99915	0.
Z99919	0.80122200	Z99918	4.9647E-04	VS1PUI	0.
Z99921	0.60090100	Z99920	0.11261300	IDCR1IC	0.
Z99924	0.38249300	Z99923	0.00397265	U1IC	0.99000000
Z99926	1.60674000	Z99925	0.12826900	EAFM1IC	1.00000000
Z99933	0.40812500	Z99932	0.01081880	XMV2I	0.31609000
Z99935	7650.92000	Z99934	37.6953000	NGGL2I	7193.84000
Z99937	98.0760000	Z99936	3.63216000	PS3WC2I	68.0631000
Z99939	0.00540942	Z99938	1.2422E-04	EMFFB2I	0.
Z99941	55.7961000	Z99940	1.17467000	ALPHA2I	40.9791000
Z99944	-345.117000	Z99943	-0.01869810	TGLAG2I	-345.140000
Z99948	-0.71828700	Z99947	-0.08995550	TABTR2I	0.
Z99952	563.829000	Z99951	81.0201000	QMAPL2I	0.
Z99954	3599.76000	Z99953	0.22549100	NPTL2I	3600.00000
Z99956	27.4282000	Z99955	0.55030300	P54LL2I	21.7097000
Z99958	27.0445000	Z99957	0.54005200	P54L2I	21.3889000
Z99964	1480.31000	Z99963	1.80771000	T51PL2I	1416.04000
Z99967	2015.24000	Z99966	6.35242000	T4PL2I	1875.14000
Z99973	-0.04550120	Z99972	0.03381350	NERR2I	0.
Z99981	0.18034100	Z99980	0.03046940	TMECH1IC	0.
Z99986	1.00000000	Z99985	0.	FUEL1IC	0.
Z99988	1.35554000	Z99987	0.00328422	EAFG2IC	1.00000000
Z99990	1.47432000	Z99989	0.00403643	EAFG1IC	1.00000000

Algebraic Variables

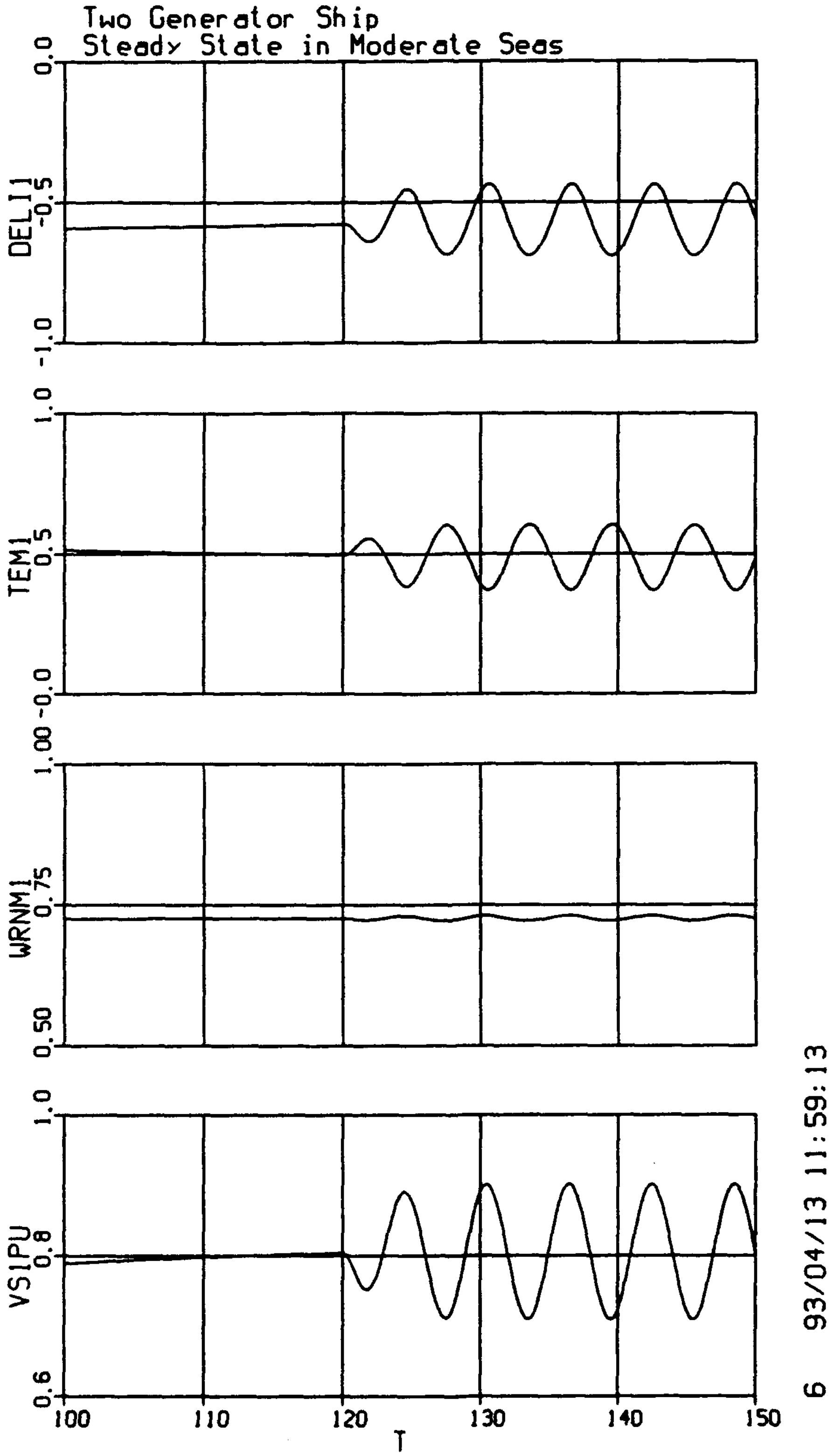
ommon Block /ZZCOMU/

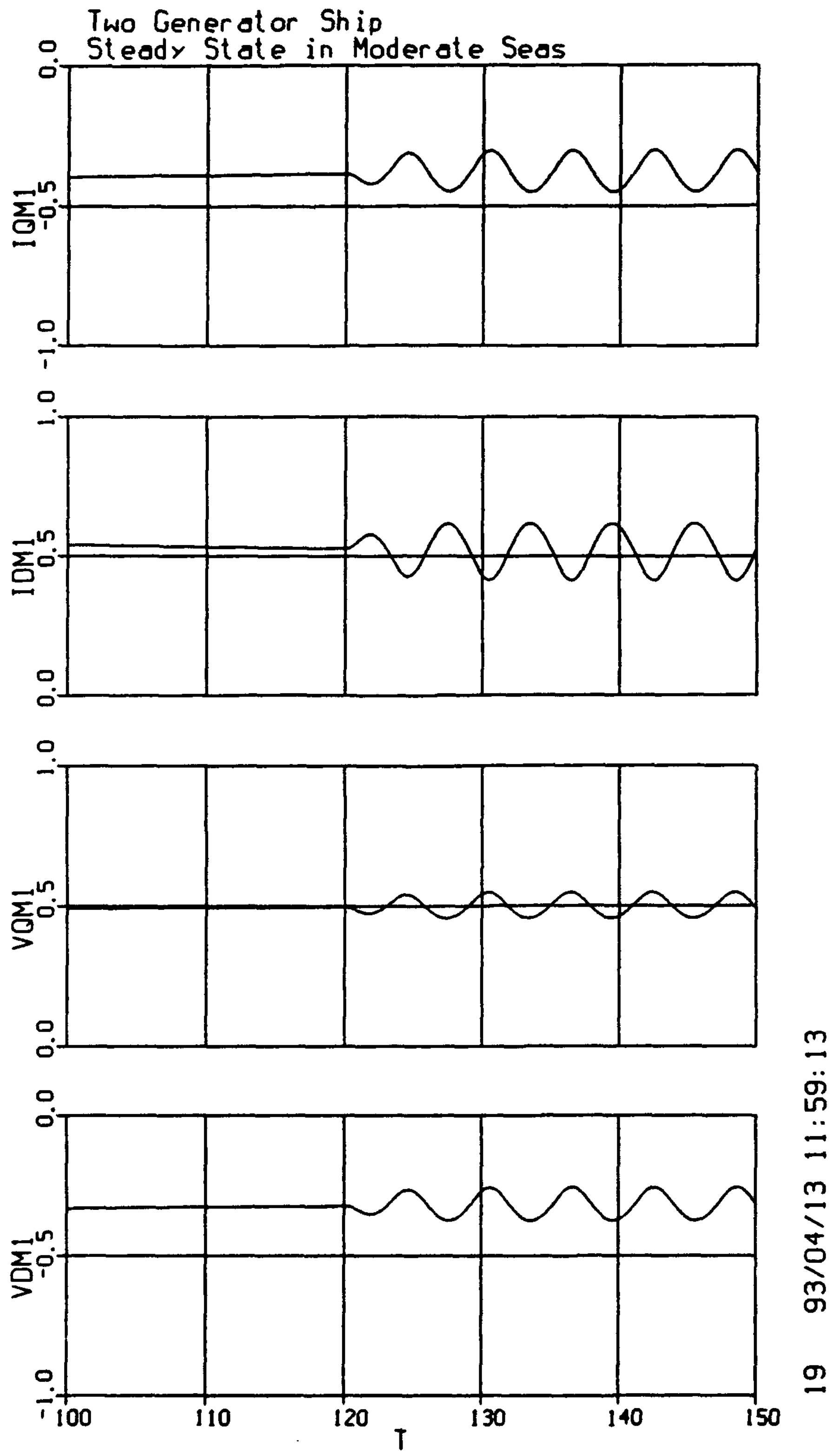
AFL2	0.16580000	AFRL2	0.16177100	ALPHA2	55.7961000
ALPHA2LL	13.0000000	ALPHA2UL	120.000000	ALPHAG1	20.7143000
ALPHAG2	54.0000000	ALPHAM1	18.4545000	ARLLG2I	0.31609000
BASEKWG1	2500.00000	BASEKWG2	16200.0000	BASEKWM1	14914.0000
BASENG1	900.000000	BASENG2	3600.00000	BASENM1	150.000000
BASEQM1	949455.000	BASEVG1	450.000000	BASEVG2	4160.00000
BASEVM1	5000.00000	BETAI1	2.20000000	BETAR1	1.17830000
CQLID2	2.8143E-05	CYL1	8.00000000	DELAY1	0.47403000
DELG1	0.14596800	DELG2	0.14855900	DELI1	-0.56631600
DELR1	0.20206400	DELTA2	1.00000000	DELV	1.0000E-04
DELVTQ2	0.	DELWF2	80.2798000	DELWF2I	0.
DFL2	-0.77088900	DFRL2	-0.18340900	DN2	0.31122000
DNGG2	7660.77000	DNPT2	0.31122000	DNREF2	180.000000
DQ4S2	-20.3900000	DQHR22	90.7505000	DQPTR2	4761.81000
DRLLG2I	0.31609000	DRPMDT2	3.0479E-04	DT4HS2	-5.38298000
DT51HS2	-3.17897000	E02I	0.	E212	0.00711710
E222	0.42702600	E232	0.14234200	E52	8.35195000
E62	0.	E72	0.14359100	E82	0.
E92	0.49969500	EAFERRM1	6.4135E-05	EAFG1	1.47432000
EAFG1D	0.00403643	EAFG2	1.35554000	EAFG2D	0.00328422
EAFM1	1.60674000	EAFM1D	0.12826900	EAFM1MAX	4.00000000
EAFM1MIN	0.	EAFMAXG1	3.00000000	EAFMAXG2	3.00000000
EAFMING1	0.	EAFMING2	0.	EAFSM1	1.60680000
EDPPG1D	0.01313510	EDPPG2D	0.01724740	EDPPM1D	-0.05109890
EI1	0.58378600	EISM1	1.00000000	EMFFB2	0.00540942
EMFSAT2	4.7579E-04	ENGG2	4.7579E-04	ENPT2	7.19953000
ENPT2I	7.20000000	EPM1	1.28377000	EQPG1D	0.00710219
EQPG2D	0.00198796	EQPM1D	0.00350416	EQPPG1D	0.00520087
EQPPG2D	0.00142611	EQPPM1D	-0.00344501	ER1	0.91761100
ERRBOUND	1.0000E-04	ERX2	4.7579E-04	FARG0	0
FARG1	1	FARG2	2	FARG3	3
FARGS0	0	FARGS1	1	FARGS2	2
FARGS3	3	FUEL1	0.25527800	FUEL1MAX	1.00000000
FUEL1MIN	0.	FUELAG1	0.05042310	G12	0.22000000
G32	0.50000000	G52	0.50000000	GBETAR1	30.0000000
GEAFG1	100.000000	GEAFG2	100.000000	GEAFM1	100.000000
GSPEED1	25.0000000	HG1	1.91000000	HG2	0.92400000
HHPS	0.51678100	HM1	1.28978000	HP2	2993.90000
HP2B	25000.0000	HP2D	2993.90000	HP2I	0.
HP2ORD	0.	HP2ORDI	0.	HPT2ORD	2993.90000
IAJXQM1	0.63051500	ICLIM2	70.0000000	ICNTRL2	-0.04550120
ICNTRL2I	0.	ID2GR	1.00000000	IDC1D	0.11471900
IDCR1	0.60090100	IDCR1D	0.11261300	IDCR1DMAX	10.0000000
IDCR1DMIN	-10.0000000	IDCR1MAX	1.00000000	IDCR1MIN	0.
IDG1	0.25876800	IDG1IC	0.	IDG1M1	0.48196400
IDG2	0.20375800	IDG2ERR	0.	IDG2IC	0.
IDG2M1	0.26601900	IDL2	0.14877000	IDM1	0.52433200
IDM1IC	0.	IDR1	0.59921300	IDSM1	0.53570000
IDXM1	0.32302700	IERR1	0.01275110	IERR1IC	0.
IGG2	566.778000	IITID2	580.484000	IQG1	0.14579700
IQG1IC	0.	IQG1M1	0.27155200	IQG2	0.09087750
IQG2ERR	0.	IQG2IC	0.	IQG2M1	0.11864600

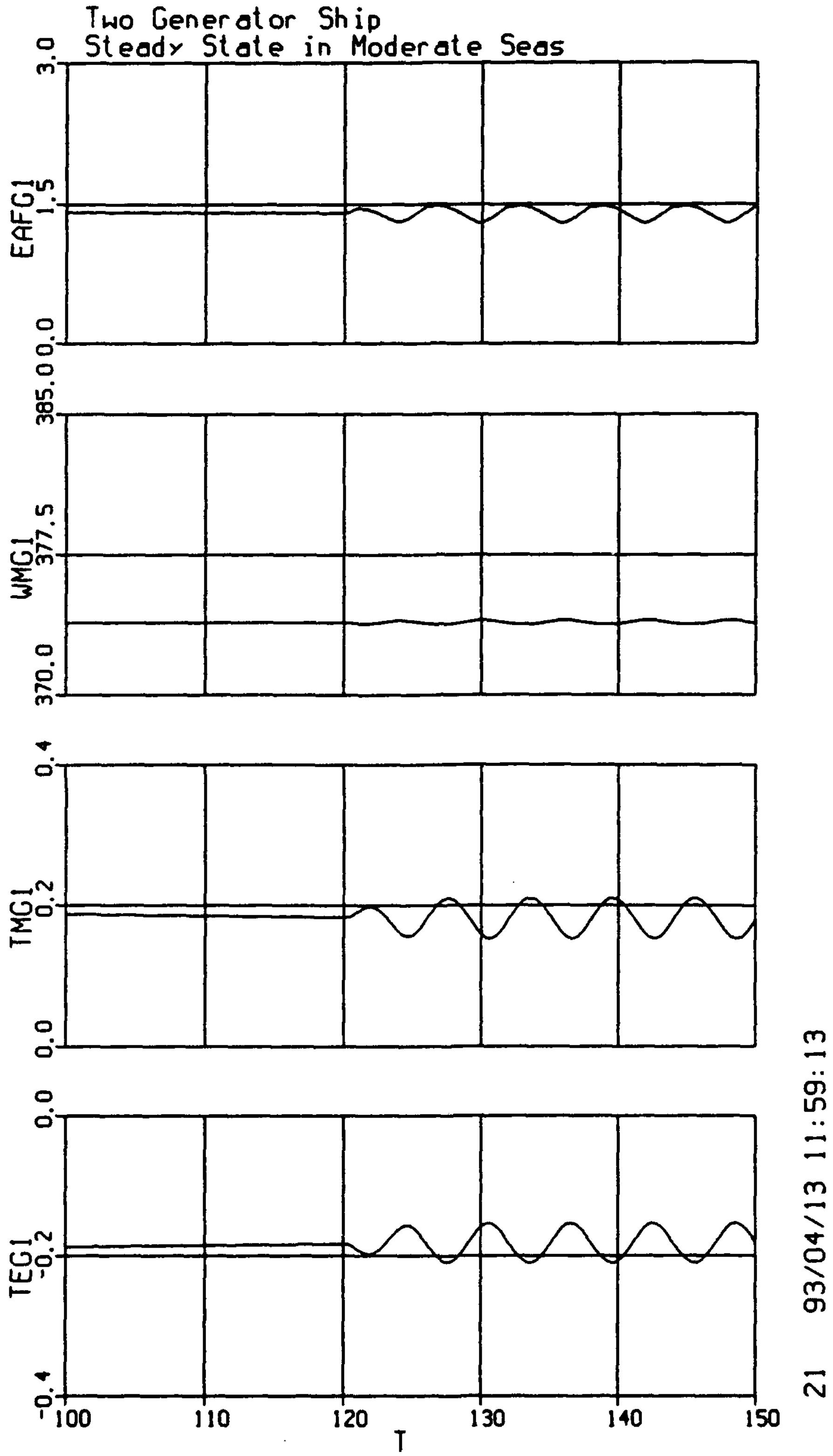
IQL2	0.14214100	IQM1	-0.38165900	IQM1IC	0.
IQR1	0.24805800	JJG	16505.0000	JJPROP	1.3130E+06
JJPS	1.4790E+06	JJPT2	2171.50000	JJSHFT	166000.000
K00RES	0.	K01RES	0.20233900	K02RES	-0.05737380
K03RES	0.96980600	K04RES	-0.23175100	K05RES	8.65721000
K06RES	-5.19908000	K07RES	-23.5963000	K08RES	15.9458000
K09RES	20.3595000	K10RES	-15.1637000	KALARM2	0
KC12	0.50000000	KDFRQ	1.57080000	KGC	32.1740000
KGOV1	0.20000000	KHOLDPI2	1.00000000	KI	307.240000
KIG1M1	1.86253000	KIG2M1	1.30556000	KKWG1M1	0.16762800
KKWG2M1	1.08623000	KPNGG2	0.01017600	KQHP	5252.10000
KRAT2	0.16000000	KRATE2	10.0000000	KSHTDN2	0
KTBL2	0	KTURBO1	0.50000000	KVG1M1	0.09000000
KVG2M1	0.83200000	KVSHIP	0.00754970	KZG1M1	0.04832140
KZG2M1	0.63727300	LDOPLR	F	LFWD1	T
LHEADR	F	LHOLD2PI	F	LNGG2A	F
LPWRD2	F	LSEA	T	LT542A	F
MAXIT	10.0000000	MFKAC2	0.58200000	MFKFR2	0.17259000
MFKMV2	23.0000000	MFKN2	4.6080E-08	MFW2	159.400000
	2091.30000		13659.6000	N1	892.447000
N2	3599.80000	N2I	3600.00000	NERR2	0.20288100
NGB	3600.00000	NGG2B	9827.00000	NGGL2	7650.92000
NMAX1	950.000000	NMIN1	400.000000	NP1PU	0.75199100
NP1PUI	5.3832E-06	NP1RPM	108.827000	NP1RPMI	7.7905E-04
NP2PU	0.75199100	NP2PUI	5.3832E-06	NP2RMPI	7.7905E-04
NP2RPM	108.827000	NPRPMB	144.719000	NPRPSB	2.41200000
NPT2B	3600.00000	NPT2ORD	3600.00000	NPT2ORDI	3600.00000
NPT2R	3600.00000	NPT2RI	3600.00000	NPTL2	3599.76000
NPTQ2	158.058000	NPTQ2I	158.068000	NPTR2	3599.80000
NPTR2I	3600.00000	NREF2	3672.00000	NSET1	900.000000
P1	0.16000000	P2	14.6960000	P2T22	5.50753000
P542	27.0521000	P542I	21.3889000	P54L2	27.0445000
P54LL2	27.4282000	P54Q2	1.86637000	P54Q2I	1.47725000
P54R22	27.0809000	P54R22I	21.3889000	PAMB	14.6960000
PCNTRL2	0.10144000	PCNTRL2I	0.	PCTID2	0.01000000
PHISM1	0.20000000	PNGG2	77.8715000	PNGGR2	77.8715000
PNGGR2I	73.2049000	PS32	98.2213000	PS32I	68.0631000
PS3R22	98.2213000	PS3R22I	68.0631000	PS3WC2	98.0760000
PWRD2	11.9756000	PWRD2I	0.	Q1	0.12000000
Q42	7727.45000	Q4R22	7727.45000	QCAL2	3105.31000
QCAL2I	0.	QGB	36520.0000	QH2	70.3605000
QLID2	364.689000	QLID2I	364.730000	QMAP2	566.259000
QMAP2I	0.	QMAPL2	563.829000	QP1	615581.000
QP1F	9902.20000	QP1FI	92443.6000	QP1I	-0.23332300
QP1PU	0.49680800	QP1PUI	-1.8831E-07	QP2	615581.000
QP2F	9902.20000	QP2FI	92443.6000	QP2I	-0.23332300
QP2PU	0.49680800	QP2PUI	-1.8831E-07	QPBASE	1.2391E+06
QPSBAF	92466.4000	QPT2	4751.70000	QPT2B	36473.0000
QPT2I	364.730000	QPT2PU	0.13011200	QREF2	45000.0000
RDC1	0.02000000	RS1PU0	3.86325000	RS1PU1	-3.55514000
RS1PU2	0.36779100	RS1PU3	0.16232200	RS1PU	0.83822800
RS1PUI0	0.	RS1PUI1	0.	RS1PUI2	0.
RS1PUI3	0.	RS1PUI	0.	SEAFRQ	1.04720000
SEATIME	29.9900000	SNEGVL2	0.	SPDERR1	7.55280000
SPDREF1	0.75000000	SPEEDERR1	0.02448650	SQRTH2	1.00000000

T0SEA	120.010000	T2	518.700000	T42	2034.67000
T4P2	2040.06000	T4PL2	2015.24000	T4R22	2040.06000
T4U2	317.494000	T512	1494.29000	T51P2	1497.47000
T51PL2	1480.31000	T51Q2	0.99787700	T51R22	1497.47000
T51U2	209.707000	T542	984.969000	TABTR12	0.64804800
TALPHA2(32)	999.900000	Z99976(16)	108.000000	Z99977(16)	999.900000
TAMB	59.0000000	TAUBETAR1	0.01000000	TAUEAFG1	0.10000000
TAUEAFG2	0.10000000	TAUEAFM1	0.05000000	TAUGOV1	2.00000000
TAUSPEED1	0.10000000	TC12	3.00000000	TDOPG1	3.79000000
TDOPG2	3.19000000	TDOPM1	2.10000000	TDOPPG1	0.38000000
TDOPPG2	0.04000000	TDOPPM1	0.03900000	TDT542(48)	99999.0000
Z99968(36)	68.3000000	Z99969(12)	99999.0000	TEG1	-0.18102100
TEG2	-0.11960800	TEG2IC	0.	TEM1	0.48552300
TESM2	4368.10000	TESM2I	0.	TGLAG2	7.20041000
THDOT22	1.14064000	THET2N	1.00000000	THETA2	1.00000000
THTA2V	1.00000000	TIC2	55.9891000	TIC2LL	13.0000000
TIC2UL	113.500000	TICMD2	55.9891000	TICMD2I	13.0000000
TICN2	0.05593920	TICN2I	0.	TICRL2LL	-89.0000000
TICRL2UL	22.5000000	TICS2	55.9332000	TICS2I	13.0000000
TMAP(116)	950.000000	Z99997(96)	0.92280000	Z99998(20)	950.000000
TMG1	0.18034100	TMM1	-0.49680800	TMM2	-0.49680800
TORQ1	0.19478400	TP1PU	0.45199400	TP1PUI	0.
TP2PU	0.45199400	TP2PUI	0.	TQOPPG1	0.19000000
TQOPPG2	0.09000000	TQOPPM1	0.19300000	TSEA	10.0000000
TSTOP	150.000000	TURBOLAG1	0.42360600	TUT4H2	0.25599600
TUT51H2	0.10533900	TVS0REF	696.262000	U1	0.38249300
U1D	0.00397265	UMAX1	0.99000000	UMIN1	0.
VDBIC	0.	VDBUS	0.15935100	VDERR	0.
VDG1	0.14476000	VDG2	0.14748700	VDM1	-0.31321700
VDR1	0.18415700	VERRG1	0.01474720	VERRG2	0.01355870
VI1	-0.56824200	VN2	7.34400000	VNSF2	500.000000
VQ2	9.00000000	VQBIC	1.00000000	VQBUS	0.95886300
VQERR	0.	VQG1	0.98466900	VQG2	0.98546600
VQM1	0.49264800	VQR1	0.89894100	VQSF2	5000.00000
VR1	0.58051600	VR2	0.50000000	VRATE2	0.
VRSF2	360.000000	VS1PU0	1.0000E-05	VS1PU10	0.11040400
VS1PU10I	0.	VS1PU2	0.64357200	VS1PU2I	0.
VS1PU3	0.51629200	VS1PU3I	0.	VS1PU4	0.41418400
VS1PU4I	0.	VS1PU5	0.33227100	VS1PU5I	0.
VS1PU6	0.26655700	VS1PU6I	0.	VS1PU7	0.21384000
VS1PU7I	0.	VS1PU8	0.17154900	VS1PU8I	0.
VS1PU9	0.13762100	VS1PU9I	0.	VS1PU	0.80222900
VT12	0.94481100	VTG1	0.99525300	VTG2	0.99644100
VTOP2	0.	VTREFG1	1.01000000	VTREFG2	1.01000000
VTRQGS2	0.	W42	58.9811000	W4R22	58.9811000
W542	65.9670000	W54R22	65.9670000	WAVE	12.0000000
WEFSEA	1.04720000	WESEA	-0.00125678	WESEAMG	0.12000000
WESMAX	0.12000000	WFAC2	4437.68000	WFSR22	3279.88000
WFUEL2	3360.16000	WFUEL2I	2185.21000	WMG1D	-0.06713930
WMG2	376.979000	WMM1D	-1.64936000	WO	377.000000
WRN2ORD	1.00000000	WRN2ORDIC	1.00000000	WRNG1	0.99158600
WRNG2	0.99994400	WRNG2IC	1.00000000	WRNM1	0.72551300
WRNM2	0.72551300	XDC1	1.68000000	XDG1	1.63000000
XDG2	1.77000000	XDM1	1.76000000	XDMXQM1	0.60300000
XDPG1	0.25000000	XDPG2	0.18000000	XDPM1	0.60800000

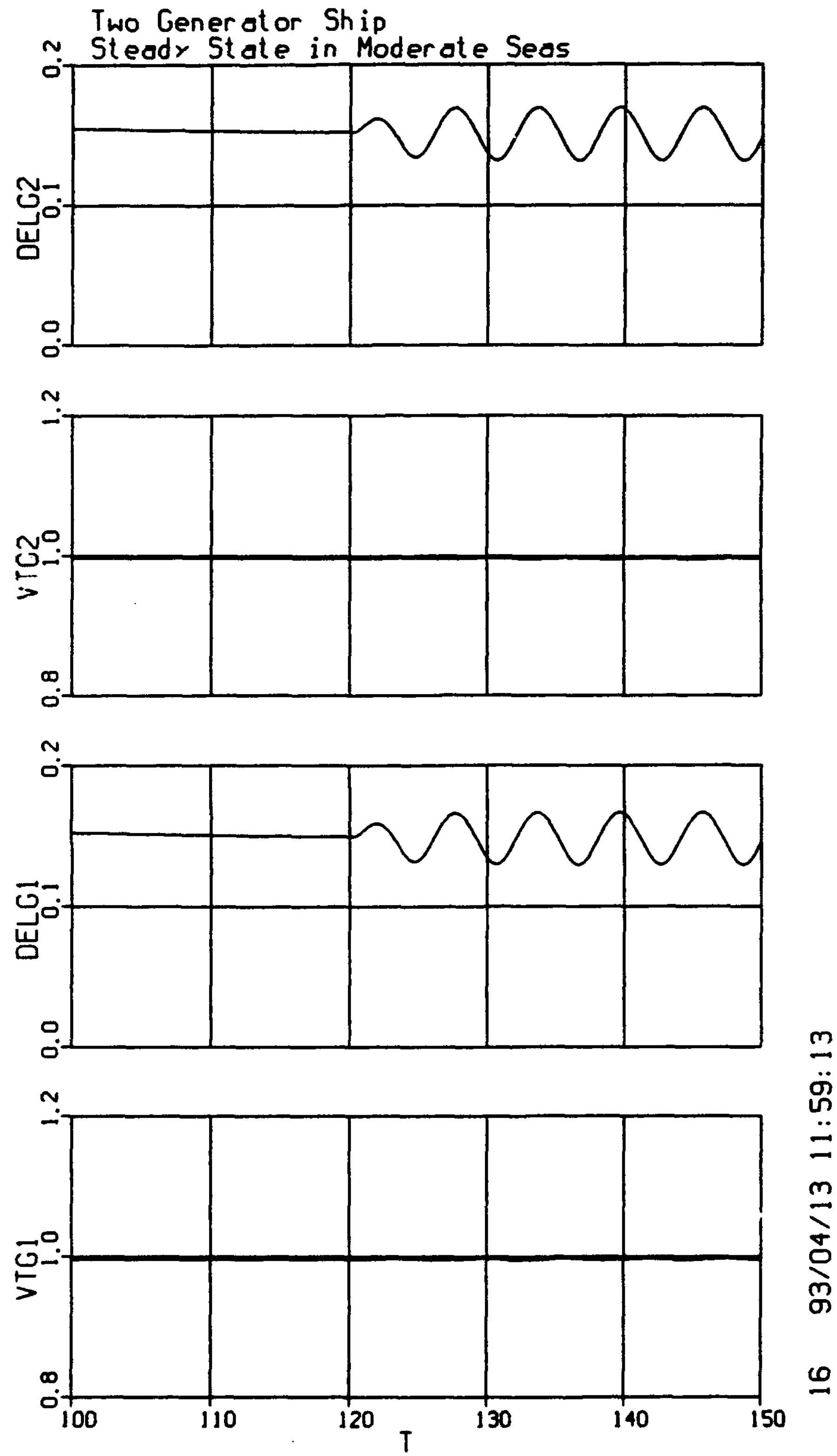
XDPPG1	0.18000000	XDPPG2	0.15000000	XDPPM1	0.54200000
XG1	0.10000000	XG2	0.10000000	XK3L2	2.20000000
XL1	0.10000000	XLG1	0.07500000	XLG2	0.13000000
XLM1	0.33700000	XMV2	0.41353400	XQG1	1.01000000
XQG2	1.64000000	XQM1	1.15700000	XQPPG1	0.28000000
XQPPG2	0.15000000	XQPPM1	0.49400000	XVS0REF	207.220000
Z99887	0.26599300	Z99888	-1.16592000	Z99889	0.26602600
Z99890	0.26599300	Z99891	0.26603100	Z99893	1
Z99894	0.11864600	Z99895	-1.15651000	Z99896	0.11871800
Z99897	0.11858400	Z99898	0.11864500	Z99900	1
Z99901	0.95886300	Z99902	-0.69422000	Z99903	0.95875600
Z99904	0.95901600	Z99905	0.95879200	Z99907	1
Z99908	0.15933500	Z99909	-0.95042100	Z99910	0.15935500
Z99911	0.15933500	Z99912	0.15933900	Z99914	1
Z99945	7.19953000	Z99946	7.20041000	Z99949	0.62106100
Z99950	0.64804800	Z99960	47	Z99961	40
Z99962	49.6193000	Z99970	21	Z99971	55.9332000
Z99974	18	Z99975	13.0000000	Z99982	115
Z99983	99	Z99984	0.19478400	ZZSEED	55555555

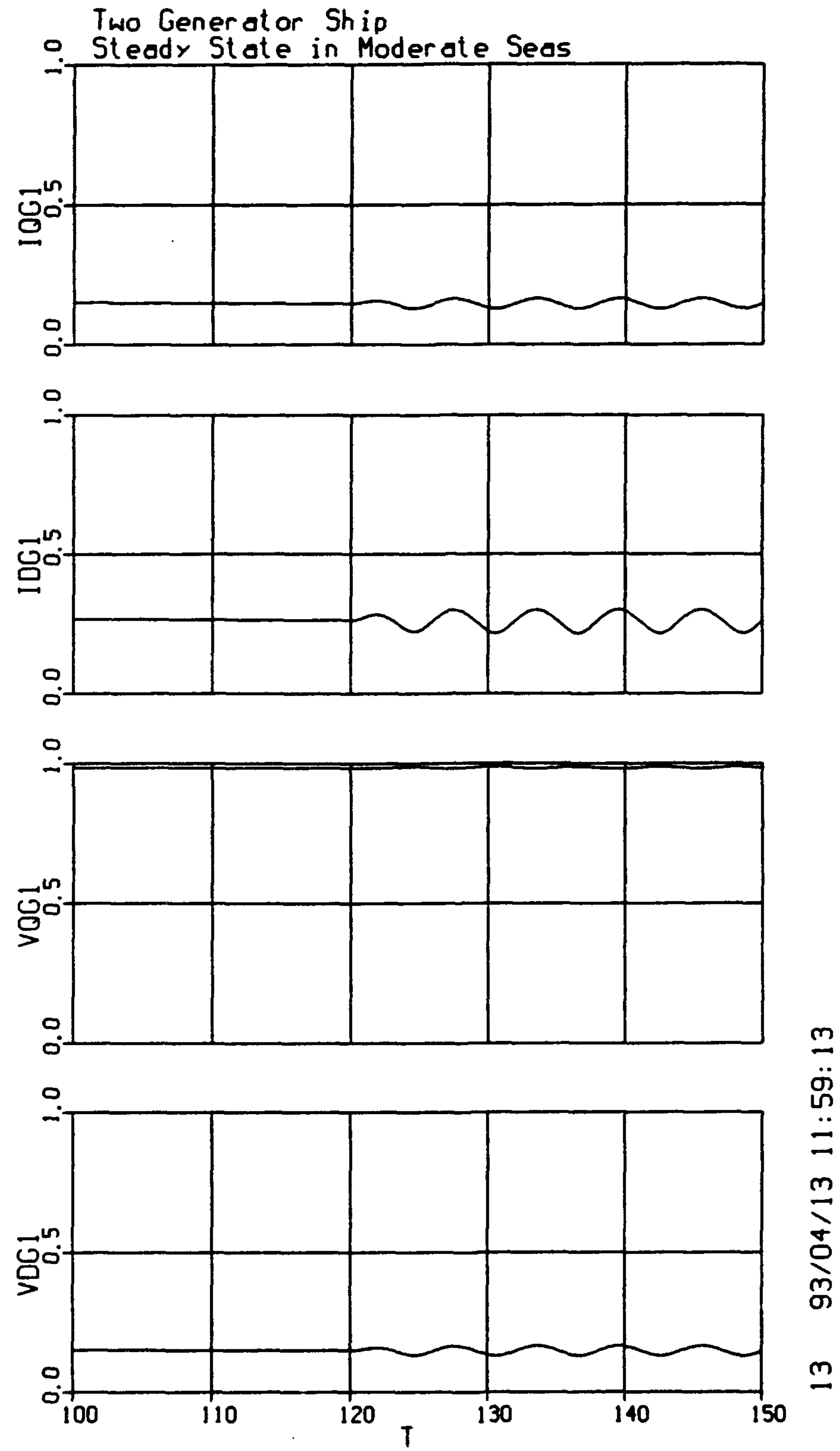

Two Generator Ship
Steady State in Moderate Seas
DEL11
0.0
-0.5
-1.0
TEM1
1.0
0.5
-0.0
WRNM1
1.00
0.75
0.50
VS1PU
1.0
0.8
0.6
100
110
120
130
140
150
T
93/04/13 11:59:13
6

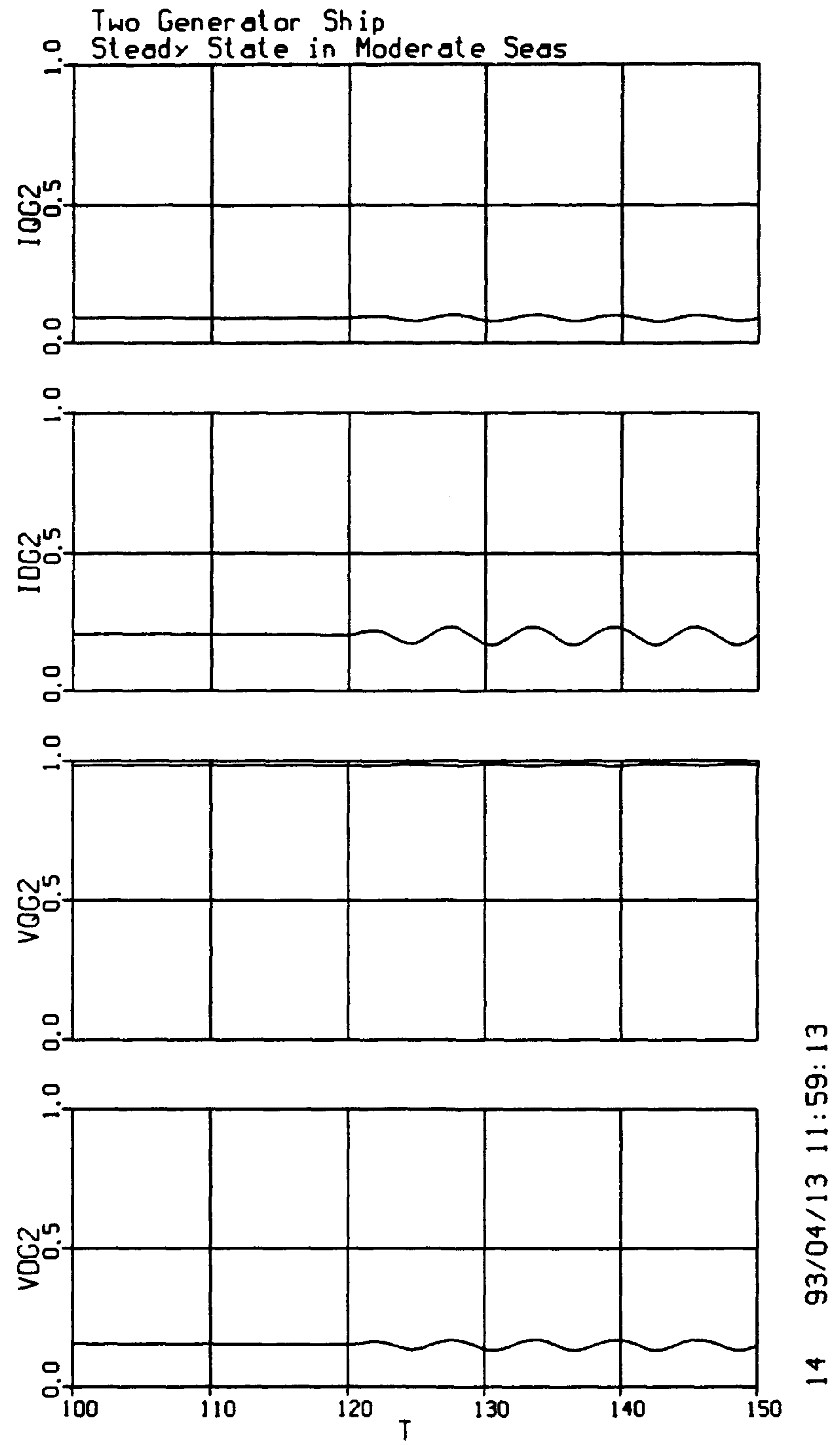

Two Generator Ship
Steady State in Moderate Seas
IQM1
IDM1
VQM1
VDM1
0.0
-0.5
-1.0
1.0
0.5
100
110
120
130
140
150
T
19 93/04/13 11:59:13

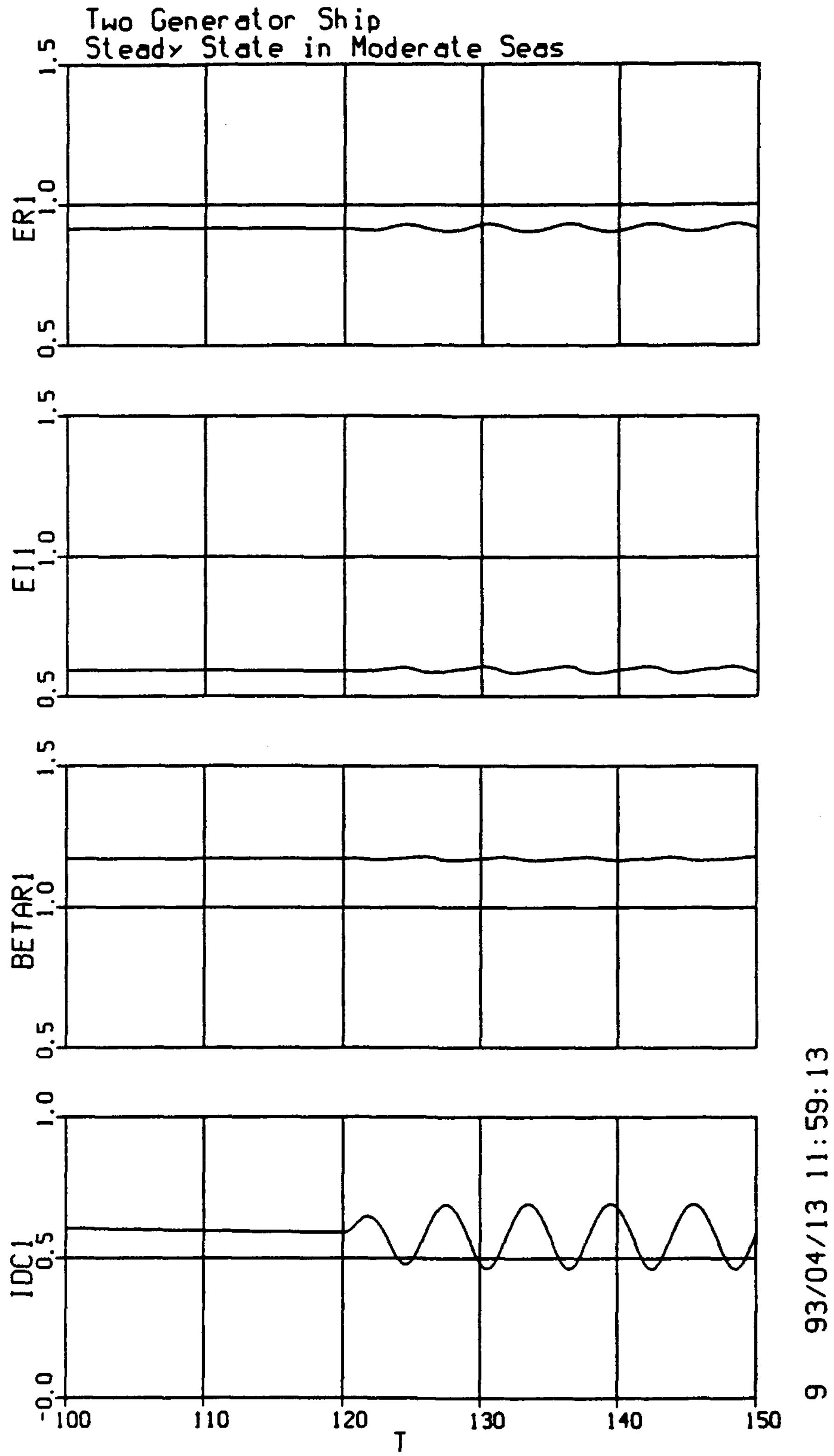


Two Generator Ship
Steady State in Moderate Seas
EAFG1
3.0
1.5
0.0
WMG1
385.0
377.5
370.0
TMG1
0.4
0.2
0.0
TEG1
0.0
-0.2
-0.4
100
110
120
130
140
150
T
93/04/13 11:59:13
21


Two Generator Ship
Steady State in Moderate Seas
DELG2
0.0
0.1
0.2
VTG2
0.8
1.0
1.2
DELG1
0.0
0.1
0.2
VTG1
0.8
1.0
1.2
100
110
120
130
140
150
T
16 93/04/13 11:59:13


Two Generator Ship
Steady State in Moderate Seas
IQG1
IDG1
VQG1
VDG1
0.0
0.5
1.0
100
110
120
130
140
150
T
93/04/13 11:59:13
13


Two Generator Ship
Steady State in Moderate Seas
IQG2
IDG2
VQG2
VDG2
0.0
0.5
1.0
100
110
120
130
140
150
T
93/04/13 11:59:13
14



Two Generator Ship
Steady State in Moderate Seas
ER1
EI1
BETAR1
IDC1
1.5
1.0
0.5
-0.0
100
110
120
130
140
150
T
93/04/13 11:59:13

D.3 Two Mode Speed Control in Moderate Seas

System 2a: Steady state in moderate seas (spderfl = 0.75)

T	180.000000	ZZTICG	0.	CINT	0.10000000
ZZIERR	F	ZZNBLK	1	ZZICON	0
ZZSTFL	T	ZZFRFL	F	ZZICFL	F
ZZRNFL	F	ZZJEFL	F	ZZNIST	40
ZZNAST	0	IALG	1	NSTP	10
MAXT	0.10000000	MINT	1.0000E-08		

State Variables		Derivatives		Initial Conditions	
EDPPG1	0.20525400	Z99995	-0.00661310	EDPPG1IC	0.
EDPPG2	0.14911100	Z99992	-0.00447765	EDPPG2IC	0.
EDPPM1	-0.17283700	Z99930	0.00222434	EDPPM1IC	0.
ENPTL1	7.20019000	Z99942	-8.3446E-05	ENPTL1I	7.20000000
EQPG1	1.02884000	Z99994	0.00177130	EQPG1IC	1.00000000
EQPG2	1.04152000	Z99991	0.00157604	EQPG2IC	1.00000000
EQPM1	1.31350000	Z99929	-0.00192130	EQPM1IC	1.00000000
EQPPG1	1.01869000	Z99996	0.00174403	EQPPG1IC	1.00000000
EQPPG2	1.02238000	Z99993	0.00102810	EQPPG2IC	1.00000000
EQPPM1	1.28998000	Z99931	-0.00164469	EQPPM1IC	1.00000000
IDC1	0.40073400	Z99922	-0.00367904	IDC1IC	0.
NGG1	7847.97000	Z99965	-10.1730000	NGG1I	7193.84000
NPT1	3600.09000	Z99978	0.11062300	NPT1I	3600.00000
THMM1	40970.7000	Z99927	258.282000	THMM1IC	0.
TICRL1	61.6146000	Z99959	-0.37452700	TICRL1I	13.0000000
WMG2	373.630000	Z99979	0.02981520	WMG2IC	377.000000
WMM1	258.282000	Z99928	-9.36900000	WMM1IC	0.
Z99915	0.12000000	Z99914	1.8626E-08	Z99913	0.
Z99917	0.74532100	Z99916	0.00115009	VS1PUI	0.
Z99919	0.41686300	Z99918	-0.00461753	IDCR1IC	0.
Z99924	0.48404500	Z99923	-0.01696650	U1IC	0.99000000
Z99926	1.71990000	Z99925	0.02384190	EAFM1IC	1.00000000
Z99933	0.45454600	Z99932	-0.00268820	XMV1I	0.31609000
Z99935	7848.38000	Z99934	-10.2417000	NGGL1I	7193.84000
Z99937	114.967000	Z99936	-0.90255700	PS3WC1I	68.0631000
Z99939	-0.00134410	Z99938	1.1565E-05	EMFFB1I	0.
Z99941	61.6686000	Z99940	-0.34679800	ALPHA1I	40.9791000
Z99944	-345.150000	Z99943	0.00378426	TGLAG1I	-345.140000
Z99948	-1.32032000	Z99947	0.03114100	TABTR1I	0.
Z99952	991.809000	Z99951	-23.0062000	QMAPL1I	0.
Z99954	3600.10000	Z99953	-0.00678168	NPTL1I	3600.00000
Z99956	30.1020000	Z99955	-0.13716900	P54LL1I	21.7097000
Z99958	29.6517000	Z99957	-0.14032600	P54L1I	21.3889000
Z99964	1504.69000	Z99963	-0.47482500	T51PL1I	1416.04000
Z99967	2077.06000	Z99966	-1.65186000	T4PL1I	1875.14000
Z99973	0.01920150	Z99972	-0.01566570	NERR1I	0.
Z99981	0.25330300	Z99980	-0.00837202	TMECH2IC	0.
Z99986	1.00001000	Z99985	0.	FUEL2IC	0.
Z99988	1.42467000	Z99987	0.02460360	EAFG2IC	1.00000000
Z99990	1.57249000	Z99989	0.00110030	EAFG1IC	1.00000000

Algebraic Variables

mmon Block /ZZCOMU/

AFL1	0.17869200	AFRL1	0.17527800	ALPHA1	61.6686000
ALPHA1LL	13.0000000	ALPHA1UL	120.000000	ALPHAG1	54.0000000
ALPHAG2	20.7143000	ALPHAM1	18.4545000	ARLLG1I	0.31609000
BASEKWG1	16200.0000	BASEKWG2	2500.00000	BASEKWM1	14914.0000
BASENG1	3600.00000	BASENG2	900.000000	BASENM1	150.000000
BASEQM1	949455.000	BASEVG1	4160.00000	BASEVG2	450.000000
BASEVM1	5000.00000	BETAI1	2.20000000	BETAM1	2.20000000
BETAMINM1	1.57080000	BETAR1	1.06553000	CQLID1	2.8143E-05
CYL2	8.00000000	DELAY2	0.44939600	DELG1	0.22915800
DELG2	0.20836500	DELI1	-0.31413500	DELM1	-0.26819800
DELR1	0.29093500	DELTA2	1.00000000	DELV	1.0000E-04
DELVTQ1	0.	DELWF1	-22.5276000	DELWF1I	0.
DFL1	-0.75799800	DFRL1	-0.16990200	DN1	0.11062300
DNGG1	7845.95000	DNPT1	0.11062300	DNREF1	180.000000
DQ4S1	5.41969000	DQHR21	-24.1863000	DQPTR1	7996.48000
DRLLG1I	0.31609000	DRPMDT1	-6.2752E-05	DT4HS1	1.20182000
DT51HS1	0.71695700	DZ1	0.05000000	E01I	0.
E211	-0.00507713	E221	-0.30462800	E231	-0.10154300
E51	7.91686000	E61	0.	E71	0.14398800
E81	0.	E91	0.74022600	EAFERRM1	1.1921E-05
EAFG1	1.57249000	EAFG1D	0.00110030	EAFG2	1.42467000
EAFG2D	0.02460360	EAFM1	1.71990000	EAFM1D	0.02384190
EAFM1MAX	3.00000000	EAFM1MIN	0.	EAFMAXG1	3.00000000
EAFMAXG2	3.00000000	EAFMING1	0.	EAFMING2	0.
EAFSM1	1.71991000	EDPPG1D	-0.00661310	EDPPG2D	-0.00447765
EDPPM1D	0.00222434	EI1	0.75219300	EISM1	1.00000000
EMFFB1	-0.00134410	EMFSAT1	-1.1638E-04	ENGG1	-1.1638E-04
ENPT1	7.20019000	ENPT1I	7.20000000	EPM1	1.50449000
EQPG1D	0.00177130	EQPG2D	0.00157604	EQPM1D	-0.00192130
EQPPG1D	0.00174403	EQPPG2D	0.00102810	EQPPM1D	-0.00164469
ER1	0.92450600	ERRBOUND	1.0000E-04	ERX1	-1.1638E-04
FARG0	0	FARG1	1	FARG2	2
FARG3	3	FARGS0	0	FARGS1	1
FARGS2	2	FARGS3	3	FUEL2	0.30261300
FUEL2MAX	1.00000000	FUEL2MIN	0.	FUELAG2	0.05044990
G11	0.22000000	G31	0.50000000	G51	0.50000000
GBETAR1	30.0000000	GEAFG1	100.000000	GEAFG2	100.000000
GEAFM1	100.000000	GLARGE1	50.0000000	GM1	1.50000000
GSMALL1	5.00000000	GSPEED1	5.00000000	HG1	0.92400000
HG2	1.91000000	HHPS	0.51678100	HM1	1.28978000
HP1	5229.24000	HP1B	25000.0000	HP1D	5229.24000
HP1I	0.	HP1ORD	0.	HP1ORDI	0.
HPT1ORD	5229.24000	IAJXQM1	0.51124700	IAM1	0.44187300
ICLIM1	70.0000000	ICNTRL1	0.01920150	ICNTRL1I	0.
ID1GR	1.00000000	IDBM1	0.	IDC1D	-0.00367904
IDCBG2	0.49866500	IDCOM1	0.41686300	IDCR1	0.41686300
IDCR1D	-0.00461753	IDCR1DMAX	5.00000000	IDCR1DMIN	-5.00000000
IDCR1MAX	0.80000000	IDCR1MIN	0.	IDG1	0.33603800
IDG1IC	0.	IDG1M1	0.43871900	IDG2	0.26773500
IDG2ERR	0.	IDG2IC	0.	IDG2M1	0.49866500
IDI1	0.35725200	IDL2	0.16406800	IDM1	0.35725200
IDM1IC	0.	IDR1	0.38665800	IDXM1	0.21542300

IERR1	0.01612920	IERR1IC	0.	IGG1	566.778000
IITID1	580.484000	IQBM1	0.	IQCBG2	0.37827200
IQG1	0.13735500	IQG1IC	0.	IQG1M1	0.17932500
IQG2	0.20309600	IQG2ERR	0.	IQG2IC	0.
IQG2M1	0.37827200	IQI1	-0.26004300	IQL2	0.12982400
IQM1	-0.26004300	IQM1IC	0.	IQR1	0.21388600
JJG	16505.0000	JJPROP	1.3130E+06	JJPS	1.4790E+06
JJPT1	2171.50000	JJSHFT	166000.000	K00RES	0.
K01RES	0.20233900	K02RES	-0.05737380	K03RES	0.96980600
K04RES	-0.23175100	K05RES	8.65721000	K06RES	-5.19908000
K07RES	-23.5963000	K08RES	15.9458000	K09RES	20.3595000
K10RES	-15.1637000	KALARM1	0	KBRAKE	1.00000000
KC11	0.50000000	KDFRQ	1.57080000	KGC	32.1740000
KGOV2	0.20000000	KHOLDPI1	1.00000000	KI	307.240000
KIG1M1	1.30556000	KIG2M1	1.86253000	KIR	2.00000000
KKWG1M1	1.08623000	KKWG2M1	0.16762800	KPNGG1	0.01017600
KQHP	5252.10000	KRAT1	0.16000000	KRATE1	10.0000000
KSHTDN1	0	KTBL1	0	KTURBO2	0.50000000
KVG1M1	0.83200000	KVG2M1	0.09000000	KVSHIP	0.00754970
KZG1M1	0.63727300	KZG2M1	0.04832140	LBRAKE	F
LCBG2	T	LDOPLR	F	LFWD1	T
LHEADR	F	LHOLD1PI	F	LNGG1A	F
LPWRD1	F	LSEA	T	LT541A	F
MAXIT	10.0000000	MFKAC1	0.58200000	MFKFR1	0.17259000
MFKMV1	23.0000000	MFKN1	4.6080E-08	MFW1	159.400000
	2091.30000		13659.6000	N1	3600.09000
N1I	3600.00000	N2	891.974000	NERR1	-0.09399410
NGB	3600.00000	NGG1B	9827.00000	NGGL1	7848.38000
NMAX2	950.000000	NMIN2	400.000000	NP1PU	0.71010000
NP1PUI	5.3832E-06	NP1RPM	102.765000	NP1RPMI	7.7905E-04
NP2PU	0.71010000	NP2PUI	5.3832E-06	NP2RMPI	7.7905E-04
NP2RPM	102.765000	NPRPMB	144.719000	NPRPSB	2.41200000
NPT1B	3600.00000	NPT1ORD	3600.00000	NPT1ORDI	3600.00000
NPT1R	3600.00000	NPT1RI	3600.00000	NPTL1	3600.10000
NPTQ1	158.072000	NPTQ1I	158.068000	NPTR1	3600.09000
NPTR1I	3600.00000	NREF1	3672.00000	NSET2	900.000000
P1	0.16000000	P2	14.6960000	P2T21	5.50753000
P541	29.6497000	P541I	21.3889000	P54L1	29.6517000
P54LL1	30.1020000	P54Q1	2.04831000	P54Q1I	1.47725000
P54R21	29.6427000	P54R21I	21.3889000	PAMB	14.6960000
PCNTRL1	-0.04699710	PCNTRL1I	0.	PCTID1	0.01000000
PHIPM1	2.20000000	PHISM1	0.20000000	PNGG1	79.8613000
PNGGR1	79.8613000	PNGGR1I	73.2049000	PS31	114.931000
PS31I	68.0631000	PS3R21	114.931000	PS3R21I	68.0631000
PS3WC1	114.967000	PWRD1	20.9170000	PWRD1I	0.
Q1	0.12000000	Q41	9340.74000	Q4R21	9340.74000
QCAL1	5462.42000	QCAL1I	0.	QGB	36520.0000
QH1	-18.7666000	QLID1	364.749000	QLID1I	364.730000
QMAP1	991.119000	QMAP1I	0.	QMAPL1	991.809000
QP1	566062.000	QP1F	9341.38000	QP1FI	92443.6000
QP1I	-0.23332300	QP1PU	0.45684400	QP1PUI	-1.8831E-07
QP2	566062.000	QP2F	9341.38000	QP2FI	92443.6000
QP2I	-0.23332300	QP2PU	0.45684400	QP2PUI	-1.8831E-07
QPBASE	1.2391E+06	QPSBAF	92466.4000	QPT1	8000.30000
QPT1B	36473.0000	QPT1I	364.730000	QPT1PU	0.21906600

QREF1	45000.0000	RDC1	0.02000000	RS1PU0	2.18094000
RS1PU1	-1.93377000	RS1PU2	0.29911900	RS1PU3	0.15098000
RS1PU	0.69726700	RS1PUI0	0.	RS1PUI1	0.
RS1PUI2	0.	RS1PUI3	0.	RS1PUI	0.
SEAFRQ	1.04720000	SEATIME	29.9909000	SNEGVL1	0.
SPDERR1IC	0.	SPDERR2	8.02618000	SPDREF1	0.75000000
SPEEDERR1	0.06490250	SQRTH2	1.00000000	SWITCHVAR1	0.09821500
T0SEA	150.009000	T2	518.700000	T41	2072.52000
T4P1	2071.32000	T4PL1	2077.06000	T4R21	2071.32000
T4U1	-82.5601000	T511	1501.41000	T51P1	1500.69000
T51PL1	1504.69000	T51Q1	1.00048000	T51R21	1500.69000
T51U1	-55.0832000	T541	989.915000	TABTR11	1.08314000
ALPHA1(32)	999.900000	Z99976(16)	108.000000	Z99977(16)	999.900000
TAMB	59.0000000	TAUBETAR1	0.01000000	TAUEAFG1	0.10000000
TAUEAFG2	0.10000000	TAUEAFM1	0.05000000	TAUFAST1	0.10000000
TAUGOV2	2.00000000	TAUSLOW1	20.0000000	TAUSPEED1	20.0000000
TC11	3.00000000	TDOPG1	3.19000000	TDOPG2	3.79000000
TDOPM1	2.10000000	TDOPPG1	0.04000000	TDOPPG2	0.38000000
TDOPPM1	0.03900000	TDT541(48)	99999.0000	Z99968(36)	68.3000000
Z99969(12)	99999.0000	TEG1	-0.20889400	TEG1IC	0.
TEG2	-0.25300100	TEM1	0.39273800	TESM1	7628.82000
TESM1I	0.	TGLAG1	7.20001000	THDOT21	-0.33675100
THET2N	1.00000000	THETA2	1.00000000	THRESHOLD1	0.10000000
THTA2V	1.00000000	TIC1	61.5772000	TIC1LL	13.0000000
TIC1UL	113.500000	TICMD1	61.5772000	TICMD1I	13.0000000
TICN1	-0.02779560	TICN1I	0.	TICRL1LL	-89.0000000
TICRL1UL	22.5000000	TICS1	61.6050000	TICS1I	13.0000000
TMAP(116)	950.000000	Z99997(96)	0.92280000	Z99998(20)	950.000000
TMG2	0.25330300	TMM1	-0.45684400	TMM2	-0.45684400
TORQ2	0.24954100	TP1PU	0.42480100	TP1PUI	0.
TP2PU	0.42480100	TP2PUI	0.	TQOPPG1	0.09000000
TQOPPG2	0.19000000	TQOPPM1	0.19300000	TSEA	10.0000000
TSTOP	180.000000	TURBOLAG2	0.39894600	TUT4H1	0.28745200
TUT51H1	0.11889900	TVSOREF	696.262000	U1	0.48404500
U1D	-0.01696650	UMAX1	0.99000000	UMIN1	0.
VDBIC	0.	VDBUS	0.24380400	VDCBG2	0.24380400
VDERR	0.	VDG1	0.22585700	VDG2	0.20597700
VDI1	-0.23242300	VDM1	-0.20641900	VDR1	0.26519300
VERRG1	0.01572600	VERRG2	0.01427130	VI1	-0.73216500
VN1	7.34400000	VNSF1	500.000000	VQ1	9.00000000
VQBIC	1.00000000	VQBUS	0.92432100	VQCBG2	0.92432100
VQERR	0.	VQG1	0.96828200	VQG2	0.97419100
VQI1	0.71538400	VQM1	0.75110900	VQR1	0.88565500
VQSF1	5000.00000	VR1	0.74016300	VRATE1	0.
VRSF1	360.000000	VS1PU0	1.0000E-05	VS1PU10	0.05350520
VS1PU10I	0.	VS1PU2	0.55677400	VS1PU2I	0.
VS1PU3	0.41545000	VS1PU3I	0.	VS1PU4	0.30999800
VS1PU4I	0.	VS1PU5	0.23131200	VS1PU5I	0.
VS1PU6	0.17259900	VS1PU6I	0.	VS1PU7	0.12878900
VS1PU7I	0.	VS1PU8	0.09609860	VS1PU8I	0.
VS1PU9	0.07170620	VS1PU9I	0.	VS1PU	0.74617300
VT12	0.91380900	VTG1	0.99427400	VTG2	0.99572900
VTM1	0.77895700	VTOP1	0.	VTREFG1	1.01000000
VTREFG2	1.01000000	VTRQGS1	0.	W41	68.6958000
W4R21	68.6958000	W541	76.8291000	W54R21	76.8291000

WAVE	12.0000000	WEFSEA	1.04720000	WESEA	-0.00114269
WESEAMG	0.12000000	WESMAX	0.12000000	WFAC1	5318.92000
WFSR21	3935.28000	WFUEL1	3912.75000	WFUEL1I	2185.21000
WMG1	377.010000	WMG2D	0.02981520	WMM1D	-9.36900000
WO	377.000000	WRN1ORD	1.00000000	WRN1ORDIC	1.00000000
WRNG1	1.00003000	WRNG1IC	1.00000000	WRNG2	0.99106000
WRNM1	0.68509700	WRNM2	0.68509700	XDC1	1.68000000
XDG1	1.77000000	XDG2	1.63000000	XDM1	1.76000000
XDMXQM1	0.60300000	XDPG1	0.18000000	XDPG2	0.25000000
XDPM1	0.60800000	XDPPG1	0.15000000	XDPPG2	0.18000000
XDPPM1	0.54200000	XG1	0.10000000	XG2	0.10000000
XK3L1	2.20000000	XL1	0.10000000	XLG1	0.13000000
XLG2	0.07500000	XLM1	0.33700000	XM1	0.10000000
XMV1	0.45320200	XQG1	1.64000000	XQG2	1.01000000
XQM1	1.15700000	XQPPG1	0.15000000	XQPPG2	0.28000000
XQPPM1	0.49400000	XVSOREF	207.220000	Z99885	0.49851500
Z99886	-0.95693800	Z99887	0.49866900	Z99888	0.49861500
Z99889	0.49870700	Z99891	1	Z99892	0.37827200
Z99893	-1.50512000	Z99894	0.37824500	Z99895	0.37828900
Z99896	0.37827100	Z99898	1	Z99899	0.92432100
Z99900	-1.14700000	Z99901	0.92426400	Z99902	0.92437000
Z99903	0.92441000	Z99905	1	Z99906	0.24380400
Z99907	-0.85880200	Z99908	0.24377200	Z99909	0.24384300
Z99910	0.24378900	Z99912	1	Z99920	0.09821500
Z99921	0.09821500	Z99945	7.20019000	Z99946	7.20001000
Z99949	1.09248000	Z99950	1.08314000	Z99960	47
Z99961	40	Z99962	51.7956000	Z99970	22
Z99971	61.6050000	Z99974	18	Z99975	13.0000000
Z99982	115	Z99983	100	Z99984	0.24954100
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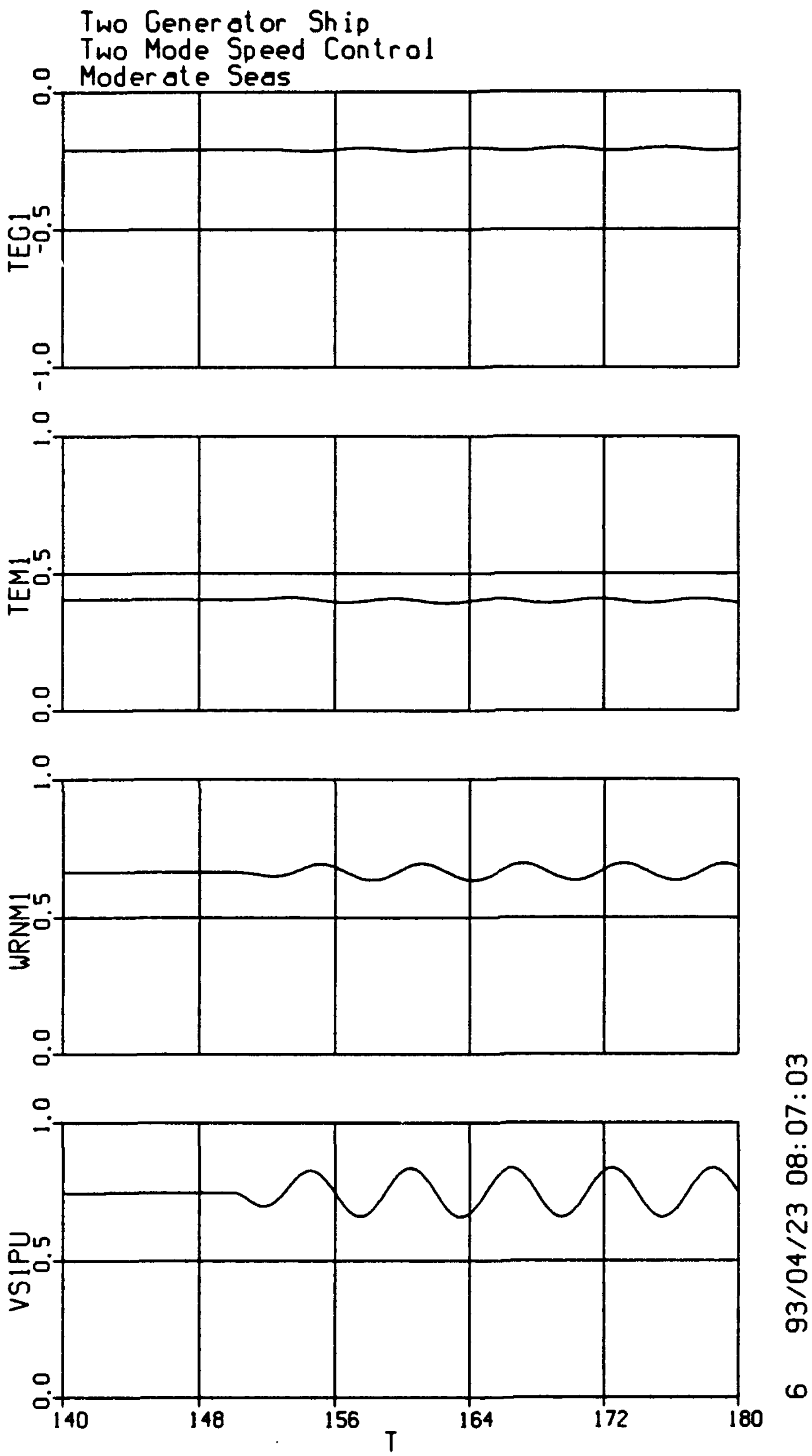

Two Generator Ship
Two Mode Speed Control
Moderate Seas
TEG1
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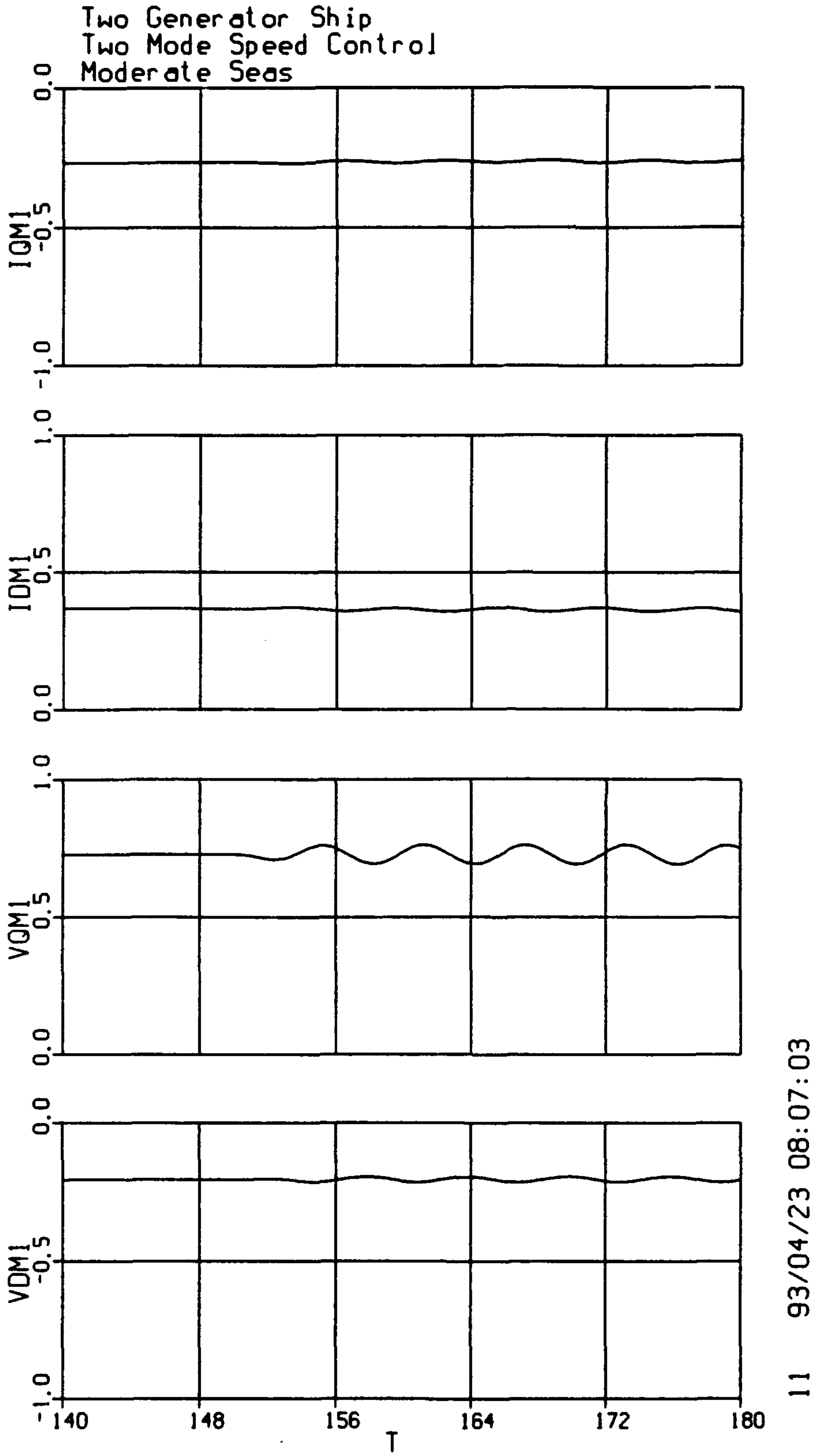
-0.5
-1.0
TEM1
1.0
0.5
0.0
WRNM1
1.0
0.5
0.0
VS1PU
1.0
0.5
0.0
140
148
156
164
172
180
T
93/04/23 08:07:03
6


Two Generator Ship
Two Mode Speed Control
Moderate Seas
IQM1
IDM1
VQM1
VDM1
0.0
-0.5
-1.0
1.0
0.5
140
148
156
164
172
180
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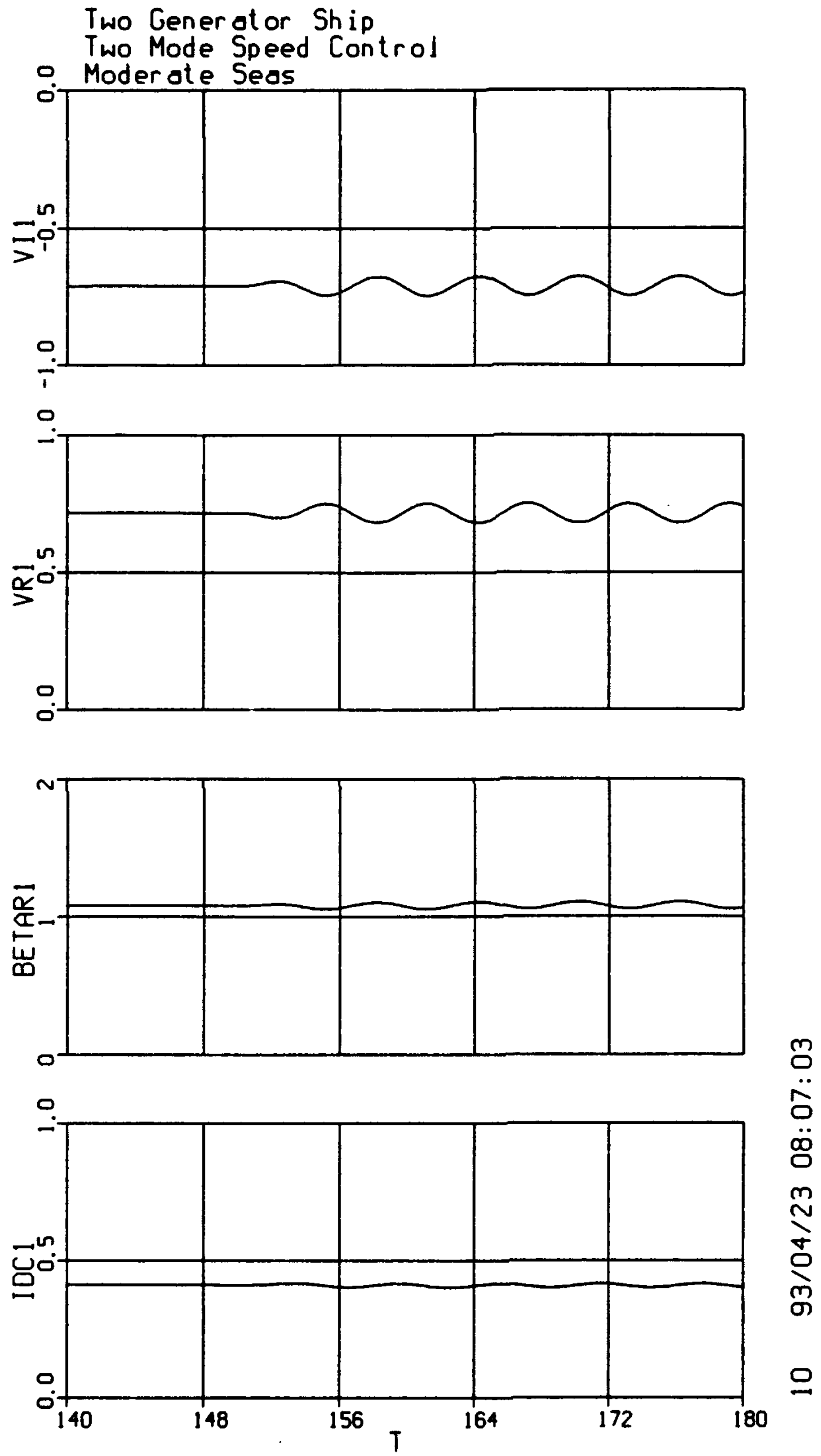
93/04/23 08:07:03
11


Two Generator Ship
Two Mode Speed Control
Moderate Seas
VI1
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-1.0
VR1
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0.5
0.0
BETAR1
2
1
0
IDC1
1.0
0.5
0.0
140
148
156
164
172
180
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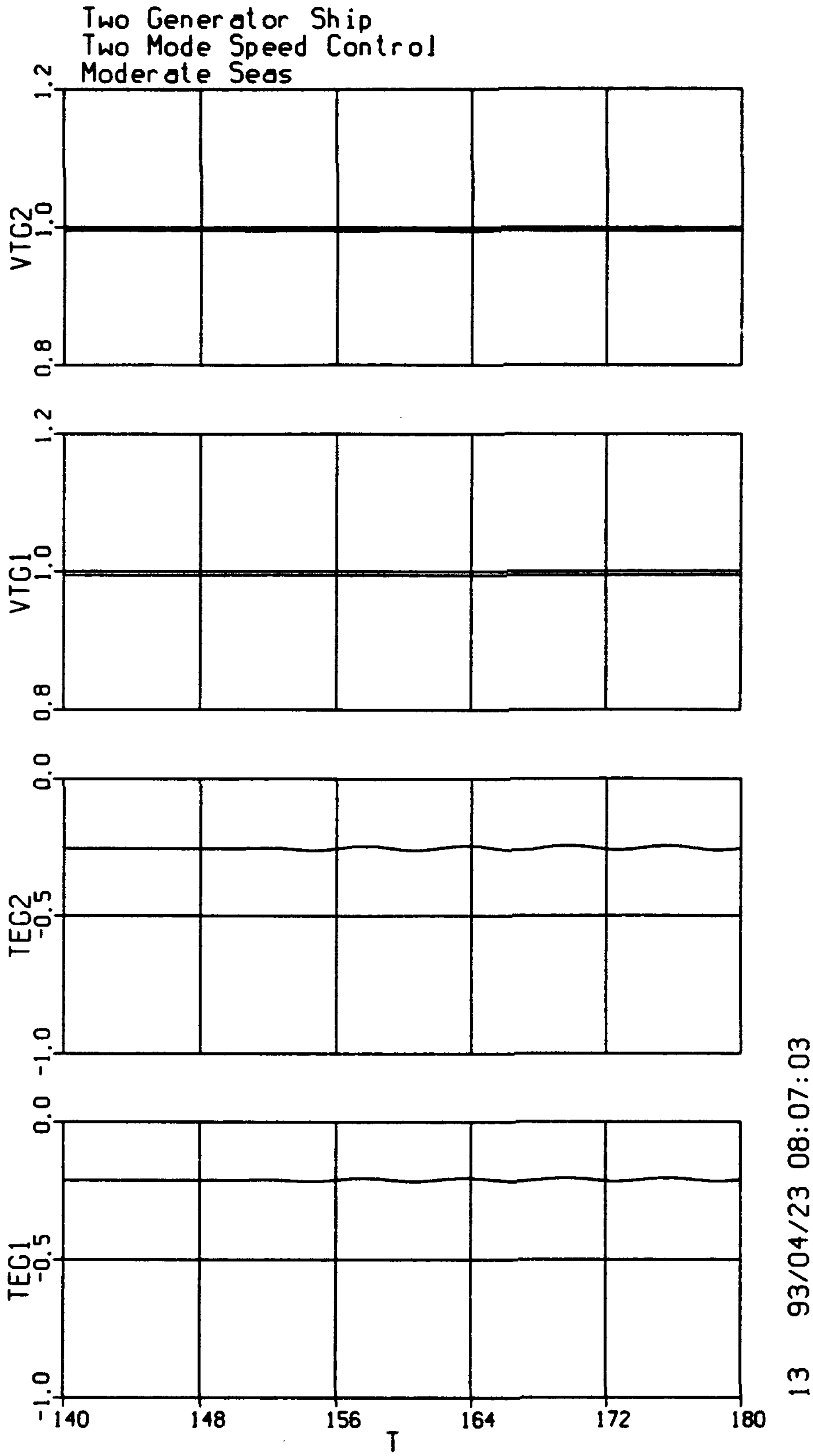
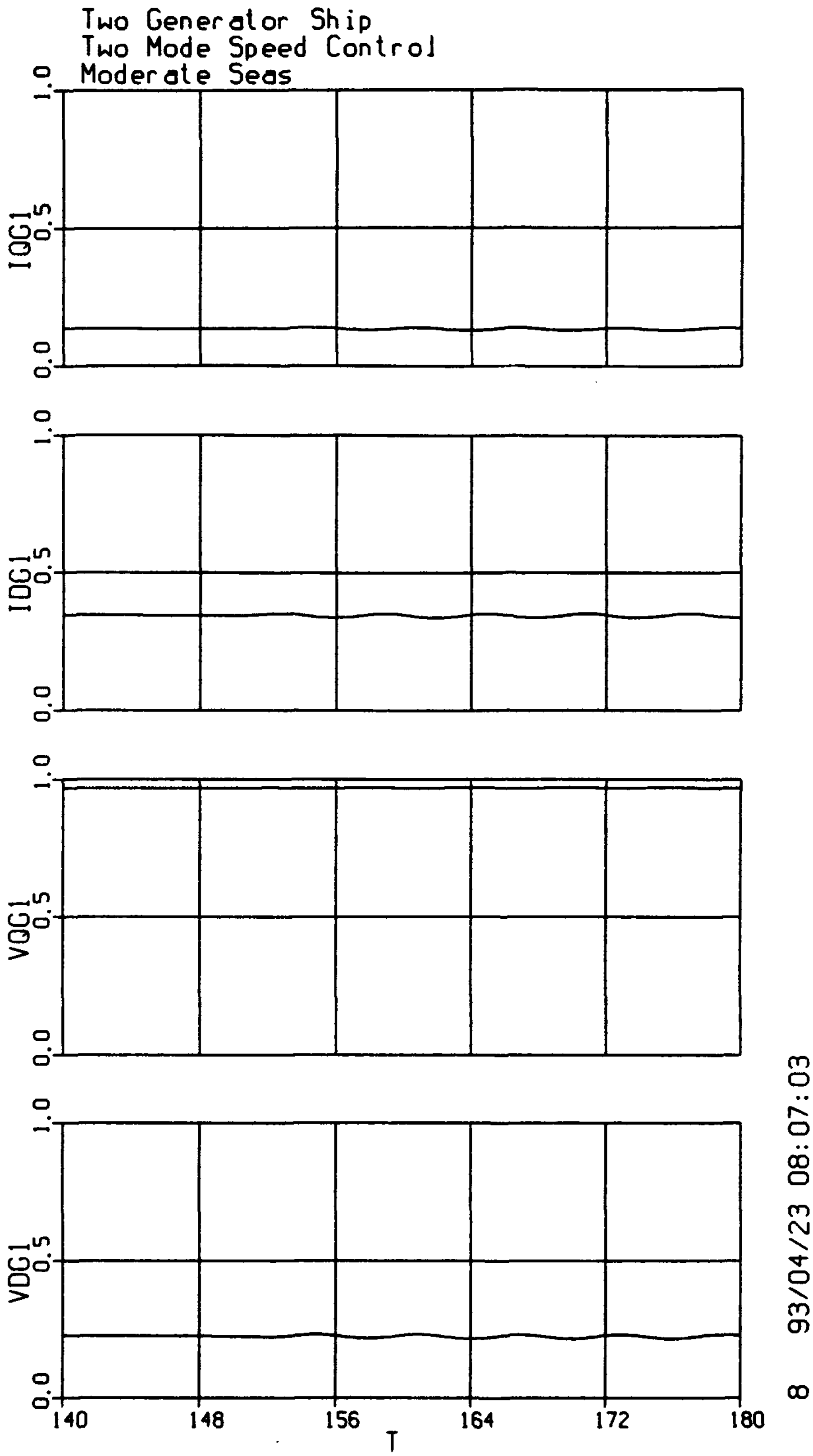
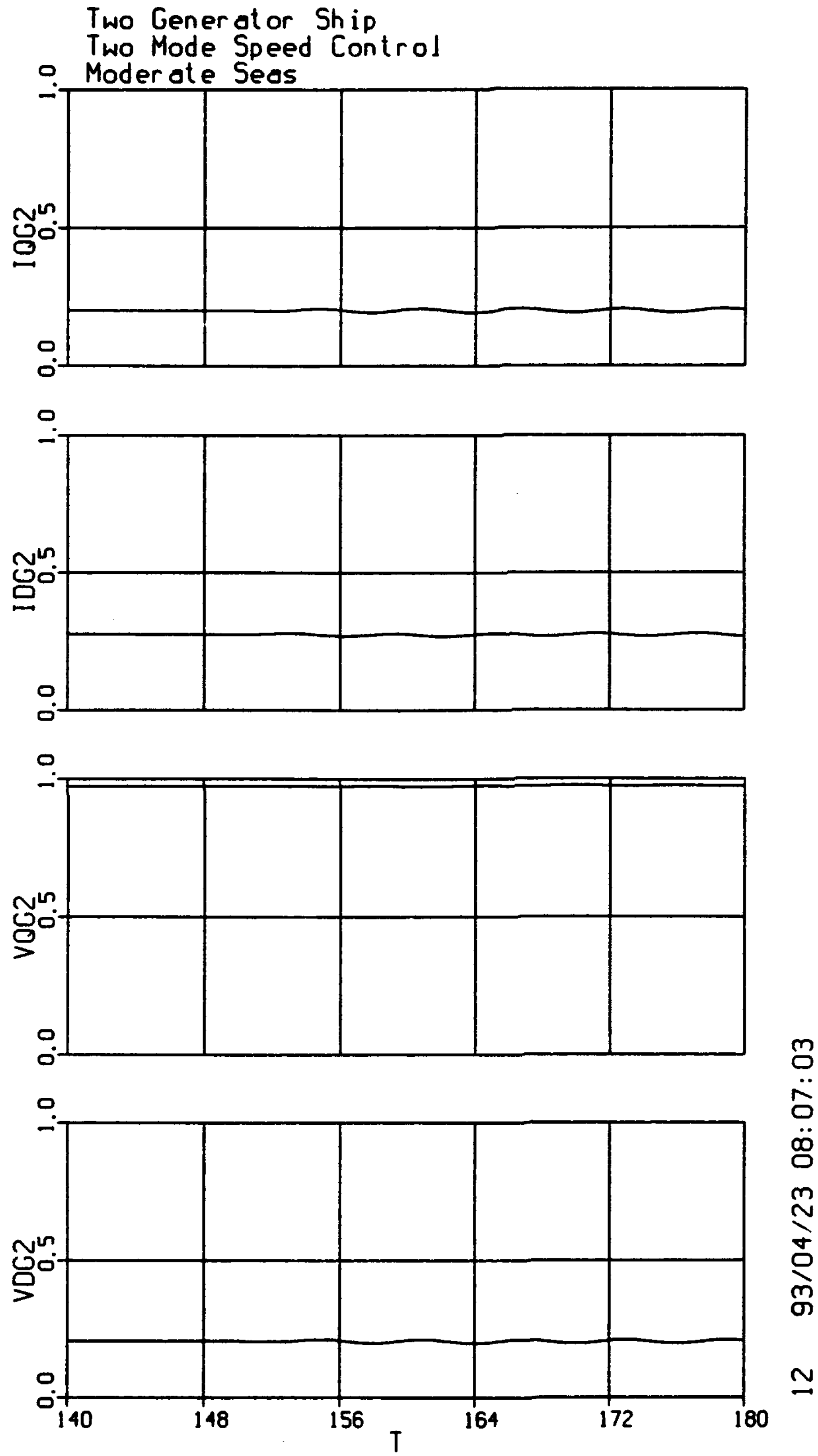
93/04/23 08:07:03
10



Two Generator Ship
Two Mode Speed Control
Moderate Seas
VTG2
1.2
1.0
0.8
VTG1
1.2
1.0
0.8
TEG2
0.0
-0.5
-1.0
TEG1
0.0
-0.5
-1.0
140
148
156
164
172
180
T
93/04/23 08:07:03
13


Two Generator Ship
Two Mode Speed Control
Moderate Seas
IQG1
IDG1
VQG1
VDG1
1.0
0.5
0.0
140
148
156
164
172
180
T
93/04/23 08:07:03
8


Two Generator Ship
Two Mode Speed Control
Moderate Seas
IQG2
IDG2
VQG2
VDG2
0.0
0.5
1.0
140
148
156
164
172
180
T
12 93/04/23 08:07:03

D.4 Speed Change from 0.4 to 0.8 pu in Moderate Seas

Two mode control: steady at 0.8 pu speed setting

T	300.000000	ZZTICG	0.	CINT	0.10000000
ZZIERR	F	ZZNBLK	1	ZZICON	0
ZZSTFL	T	ZZFRFL	F	ZZICFL	F
ZZRNFL	F	ZZJEFL	F	ZZNIST	40
ZZNAST	0	IALG	1	NSTP	10
MAXT	0.10000000	MINT	1.0000E-08		

State Variables		Derivatives		Initial Conditions	
EDPPG1	0.15365800	Z99995	-4.0719E-04	EDPPG1IC	0.
EDPPG2	0.19660600	Z99992	-3.7814E-05	EDPPG2IC	0.
EDPPM1	-0.23521400	Z99930	-0.00230476	EDPPM1IC	0.
ENPTL2	6.99170000	Z99942	0.35232300	ENPTL2I	7.20000000
EQPG1	1.08258000	Z99994	0.00108399	EQPG1IC	1.00000000
EQPG2	1.03287000	Z99991	3.2363E-04	EQPG2IC	1.00000000
EQPM1	0.99515600	Z99929	-1.2311E-04	EQPM1IC	1.00000000
EQPPG1	1.05074000	Z99996	9.7317E-04	EQPPG1IC	1.00000000
EQPPG2	1.02243000	Z99993	3.8960E-04	EQPPG2IC	1.00000000
EQPPM1	0.96294500	Z99931	-4.6449E-04	EQPPM1IC	1.00000000
IDC1	0.54774900	Z99922	0.00570955	IDC1IC	0.
NGG2	8216.29000	Z99965	382.732000	NGG2I	7193.84000
NPT2	3529.24000	Z99978	201.170000	NPT2I	3600.00000
THMM1	57118.8000	Z99927	250.926000	THMM1IC	0.
TICRL2	87.8896000	Z99959	22.5000000	TICRL2I	13.0000000
WMG1	373.443000	Z99979	-0.01753260	WMG1IC	377.000000
WMM1	250.926000	Z99928	-2.01182000	WMM1IC	0.
Z99915	0.10000000	Z99914	0.	Z99913	0.
Z99917	0.76386400	Z99916	0.00223154	VS1PUI	0.
Z99919	0.55967800	Z99918	0.00561967	IDCR1IC	0.
Z99924	0.35788100	Z99923	-0.00278652	U1IC	0.99000000
Z99926	1.55712000	Z99925	0.03337860	EAFM1IC	1.00000000
Z99933	0.57391300	Z99932	0.13427600	XMV2I	0.31609000
Z99935	8198.32000	Z99934	449.145000	NGGL2I	7193.84000
Z99937	162.229000	Z99936	22.8199000	PS3WC2I	68.0631000
Z99939	0.06713800	Z99938	-0.28698200	EMFFB2I	0.
Z99941	75.9345000	Z99940	-1.73049000	ALPHA2I	40.9791000
Z99944	-335.043000	Z99943	-16.7590000	TGLAG2I	-345.140000
Z99948	-2.73680000	Z99947	-2.96528000	TABTR2I	0.
Z99952	2743.50000	Z99951	1907.28000	QMAPL2I	0.
Z99954	3502.90000	Z99953	182.916000	NPTL2I	3600.00000
Z99956	39.0481000	Z99955	8.04158000	P54LL2I	21.7097000
Z99958	38.7879000	Z99957	4.29971000	P54L2I	21.3889000
Z99964	1543.17000	Z99963	39.1185000	T51PL2I	1416.04000
Z99967	2136.85000	Z99966	132.485000	T4PL2I	1875.14000
Z99973	-4.04560000	Z99972	11.7939000	NERR2I	0.
Z99981	0.29941200	Z99980	0.00123416	TMECH1IC	0.
Z99986	1.00001000	Z99985	0.	FUEL1IC	0.
Z99988	1.58731000	Z99987	-0.01324530	EAFG2IC	1.00000000
Z99990	1.71432000	Z99989	0.00866652	EAFG1IC	1.00000000

Algebraic Variables

mmon Block /ZZCOMU/

AFL2	0.04393850	AFRL2	0.C3831400	ALPHA2	75.9345000
ALPHA2LL	13.0000000	ALPHA2UL	120.000000	ALPHAG1	20.7143000
ALPHAG2	54.0000000	ALPHAM1	18.4545000	ARLLG2I	0.31609000
BASEKWG1	2500.00000	BASEKWG2	16200.0000	BASEKWM1	14914.0000
BASENG1	900.000000	BASENG2	3600.00000	BASENM1	150.000000
BASEQM1	949455.000	BASEVG1	450.000000	BASEVG2	4160.00000
BASEVM1	5000.00000	BETAI1	2.20000000	BETAR1	1.20480000
CQLID2	2.8143E-05	CYL1	8.00000000	DELAY1	0.43526500
DELG1	0.21576700	DELG2	0.21943000	DELI1	-0.53177800
DELR1	0.28582900	DELTA2	1.00000000	DELV	1.0000E-04
DELVTQ2	0.	DELWF2	1265.03000	DELWF2I	0.
DFL2	-0.89275100	DFRL2	-0.30686600	DN2	201.170000
DNGG2	8295.80000	DNPT2	201.170000	DNREF2	180.000000
DQ4S2	-438.265000	DQHR22	1144.31000	DQPTR2	20521.3000
DRLLG2I	0.31609000	DRPMDT2	0.26494700	DT4HS2	-75.8623000
DT51HS2	-46.5702000	DZ1	0.05000000	E02I	0.
E212	1.12458000	E222	2.20000000	E232	0.05500000
E52	5.08843000	E62	-0.44946800	E72	-0.44946800
E82	0.	E92	0.23505300	EAFERRM1	1.6689E-05
EAFG1	1.71432000	EAFG1D	0.00866652	EAFG2	1.58731000
EAFG2D	-0.01324530	EAFM1	1.55712000	EAFM1D	0.03337860
EAFM1MAX	4.00000000	EAFM1MIN	0.	EAFMAXG1	3.00000000
EAFMAXG2	3.00000000	EAFMING1	0.	EAFMING2	0.
EAFSM1	1.55714000	EDPPG1D	-4.0719E-04	EDPPG2D	-3.7814E-05
EDPPM1D	-0.00230476	EI1	0.53922700	EISM1	1.00000000
EMFFB2	0.06713800	EMFSAT2	-0.00663938	ENGG2	-0.00663938
ENPT2	7.00579000	ENPT2I	7.20000000	EPM1	1.25627000
EQPG1D	0.00108399	EQPG2D	3.2363E-04	EQPM1D	-1.2311E-04
EQPPG1D	9.7317E-04	EQPPG2D	3.8960E-04	EQPPM1D	-4.6449E-04
ER1	0.90525800	ERRBOUND	1.0000E-04	ERX2	-0.00663938
FARG0	0	FARG1	1	FARG2	2
FARG3	3	FARGS0	0	FARGS1	1
FARGS2	2	FARGS3	3	FUEL1	0.34729300
FUEL1MAX	1.00000000	FUEL1MIN	0.	FUELAG1	0.05047520
G12	0.22000000	G32	0.50000000	G52	0.50000000
GBETAR1	30.0000000	GEAFG1	100.000000	GEAFG2	100.000000
GEAFM1	100.000000	GLARGE1	50.0000000	GSMALL1	5.00000000
GSPEED1	5.00000000	HG1	1.91000000	HG2	0.92400000
HHPS	0.51678100	HM1	1.28978000	HP2	4987.44000
HP2B	25000.0000	HP2D	4987.44000	HP2I	0.
HP2ORD	0.	HP2ORDI	0.	HPT2ORD	4987.44000
IAJXQM1	0.58726000	ICLIM2	70.0000000	ICNTRL2	-4.04560000
ICNTRL2I	0.	ID2GR	1.00000000	IDC1D	0.00570955
IDCR1	0.55967800	IDCR1D	0.00561967	IDCR1DMAX	10.0000000
IDCR1DMIN	-10.0000000	IDCR1MAX	1.00000000	IDCR1MIN	0.
IDG1	0.44952600	IDG1IC	0.	IDG1M1	0.83725600
IDG2	0.34753600	IDG2ERR	0.	IDG2IC	0.
IDG2M1	0.45373000	IDL2	0.16303200	IDM1	0.48831600
IDM1IC	0.	IDR1	0.56397700	IDSM1	0.49895000
IDXM1	0.30086700	IERR1	0.01192840	IERR1IC	0.
IGG2	566.778000	IITID2	580.484000	IQG1	0.21038400
IQG1IC	0.	IQG1M1	0.39184600	IQG2	0.13194800

IQG2ERR	0.	IQG2IC	0.	IQG2M1	0.17226600
IQL2	0.13180700	IQM1	-0.35544300	IQM1IC	0.
IQR1	0.21615300	JJG	16505.0000	JJPROP	1.3130E+06
JJPS	1.4790E+06	JJPT2	2171.50000	JJSHFT	166000.000
K00RES	0.	K01RES	0.20233900	K02RES	-0.05737380
K03RES	0.96980600	K04RES	-0.23175100	K05RES	8.65721000
K06RES	-5.19908000	K07RES	-23.5963000	K08RES	15.9458000
K09RES	20.3595000	K10RES	-15.1637000	KALARM2	0
KC12	0.50000000	KDFRQ	1.57080000	KGC	32.1740000
KGOV1	0.20000000	KHOLDPI2	1.00000000	KI	307.240000
KIG1M1	1.86253000	KIG2M1	1.30556000	KIR	2.00000000
KKWG1M1	0.16762800	KKWG2M1	1.08623000	KPNGG2	0.01017600
KQHP	5252.10000	KRAT2	0.16000000	KRATE2	10.0000000
KSHTDN2	0	KTBL2	0	KTURBO1	0.50000000
KVG1M1	0.09000000	KVG2M1	0.83200000	KVSHIP	0.00754970
KZG1M1	0.04832140	KZG2M1	0.63727300	LDOPLR	F
LFWD1	T	LHEADR	F	LHOLD2PI	F
LNGG2A	F	LPWRD2	F	LSEA	T
LT542A	F	MAXIT	10.0000000	MFKAC2	0.58200000
MFKFR2	0.17259000	MFKMV2	23.0000000	MFKN2	4.6080E-08
MFW2	159.400000		2091.30000		13659.6000
N1	891.527000	N2	3529.24000	N2I	3600.00000
NERR2	70.7634000	NGB	3600.00000	NGG2B	9827.00000
NGGL2	8198.32000	NMAX1	950.000000	NMIN1	400.000000
NP1PU	0.68987600	NP1PUI	5.3832E-06	NP1RPM	99.8379000
NP1RPMI	7.7905E-04	NP2PU	0.68987600	NP2PUI	5.3832E-06
NP2RMPI	7.7905E-04	NP2RPM	99.8379000	NPRPMB	144.719000
NPRPSB	2.41200000	NPT2B	3600.00000	NPT2ORD	3600.00000
NPT2ORDI	3600.00000	NPT2R	3600.00000	NPT2RI	3600.00000
NPTL2	3502.90000	NPTQ2	153.805000	NPTQ2I	158.068000
NPTR2	3529.24000	NPTR2I	3600.00000	NREF2	3672.00000
NSET1	900.000000	P1	0.16000000	P2	14.6960000
P2T22	5.50753000	P542	38.8481000	P542I	21.3889000
P54L2	38.7879000	P54LL2	39.0481000	P54Q2	2.65705000
P54Q2I	1.47725000	P54R22	39.3498000	P54R22I	21.3889000
PAMB	14.6960000	PCNTRL2	35.3817000	PCNTRL2I	0.
PCTID2	0.01000000	PHIM1	0.40981400	PHISM1	0.20000000
PNGG2	83.6093000	PNGGR2	83.6093000	PNGGR2I	73.2049000
PS32	163.142000	PS32I	68.0631000	PS3R22	163.142000
PS3R22I	68.0631000	PS3WC2	162.229000	PWRD2	19.9498000
PWRD2I	0.	Q1	0.12000000	Q42	14734.0000
Q4R22	14734.0000	QCAL2	15109.9000	QCAL2I	0.
QGB	36520.0000	QH2	706.041000	QLID2	350.532000
QLID2I	364.730000	QMAP2	2800.72000	QMAP2I	0.
QMAPL2	2743.50000	QP1	573151.000	QP1F	9070.12000
QP1FI	92443.6000	QP1I	-0.23332300	QP1PU	0.46256500
QP1PUI	-1.8831E-07	QP2	573151.000	QP2F	9070.12000
QP2FI	92443.6000	QP2I	-0.23332300	QP2PU	0.46256500
QP2PUI	-1.8831E-07	QPBASE	1.2391E+06	QPSBAF	92466.4000
QPT2	20001.4000	QPT2B	36473.0000	QPT2I	364.730000
QPT2PU	0.54768400	QREF2	45000.0000	RDC1	0.02000000
RS1PU0	1.27270000	RS1PU1	-1.06190000	RS1PU2	0.24612500
RS1PU3	0.14109200	RS1PU	0.59801000	RS1PUI0	0.
RS1PUI1	0.	RS1PUI2	0.	RS1PUI3	0.
RS1PUI	0.	SEAFRQ	1.04720000	SEATIME	259.990000

SNEGVL2	-0.22473400	SPDERR1	8.47296000	SPDERR1IC	0.
SPDREF1	0.80000000	SPEEDERR1	0.13441400	SQRTH2	1.00000000
SWITCHVAR1	0.08485850	T0SEA	40.0100000	T2	518.700000
T42	2474.55000	T4P2	2550.41000	T4PL2	2136.85000
T4R22	2550.41000	T4U2	6621.59000	T512	1791.63000
T51P2	1838.20000	T51PL2	1543.17000	T51Q2	0.97466500
T51R22	1838.20000	T51U2	4538.03000	T542	1276.47000
TABTR12	3.91157000	TALPHA2(32)	999.900000	Z99976(16)	108.000000
Z99977(16)	999.900000	TAMB	59.0000000	TAUBETAR1	0.01000000
TAUEAFG1	0.10000000	TAUEAFG2	0.10000000	TAUEAFM1	0.05000000
TAUFAST1	0.10000000	TAUGOV1	2.00000000	TAUSLOW1	20.0000000
TAUSPEED1	20.0000000	TC12	3.00000000	TDOPG1	3.79000000
TDOPG2	3.19000000	TDOPM1	2.10000000	TDOPPG1	0.38000000
TDOPPG2	0.04000000	TDOPPM1	0.03900000	TDT542(48)	99999.0000
Z99968(36)	68.3000000	Z99969(12)	99999.0000	TEG1	-0.29958900
TEG2	-0.20323500	TEG2IC	0.	TEM1	0.44879900
TESM2	7422.15000	TESM2I	0.	TGLAG2	7.79347000
THDOT22	-1.68035000	THET2N	1.00000000	THETA2	1.00000000
THRESHOLD1	0.10000000	THTA2V	1.00000000	TIC2	92.4025000
TIC2LL	13.0000000	TIC2UL	113.500000	TICMD2	92.4025000
TICMD2I	13.0000000	TICN2	31.3361000	TICN2I	0.
TICRL2LL	-89.0000000	TICRL2UL	22.5000000	TICS2	61.0665000
TICS2I	13.0000000	TMAP(116)	950.000000	Z99997(96)	0.92280000
Z99998(20)	950.000000	TMG1	0.29941200	TMM1	-0.46256500
TMM2	-0.46256500	TORQ1	0.29994900	TP1PU	0.44679500
TP1PUI	0.	TP2PU	0.44679500	TP2PUI	0.
TQOPPG1	0.19000000	TQOPPG2	0.09000000	TQOPPM1	0.19300000
TSEA	6.00000000	TSTOP	300.000000	TURBOLAG1	0.38478900
TUT4H2	0.32034900	TUT51H2	0.13259400	TVS0REF	696.262000
U1	0.35788100	U1D	-0.00278652	UMAX1	0.99000000
UMIN1	0.	VDBIC	0.	VDBUS	0.23362500
VDERR	0.	VDG1	0.21256500	VDG2	0.21639800
VDM1	-0.27342400	VDR1	0.25524000	VERRG1	0.01715190
VERRG2	0.01585990	VI1	-0.52486900	VN2	7.34400000
VNSF2	500.000000	VQ2	9.00000000	VQBIC	1.00000000
VQBUS	0.92492800	VQERR	0.	VQG1	0.96982600
VQG2	0.97030200	VQM1	0.46476400	VQR1	0.86853000
VQSF2	5000.00000	VR1	0.53585000	VR2	0.50000000
VRATE2	0.	VRSF2	360.000000	VS1PU0	1.0000E-05
VS1PU10	0.02717780	VS1PU10I	0.	VS1PU2	0.48623100
VS1PU2I	0.	VS1PU3	0.33905000	VS1PU3I	0.
VS1PU4	0.23642100	VS1PU4I	0.	VS1PU5	0.16485700
VS1PU5I	0.	VS1PU6	0.11495500	VS1PU6I	0.
VS1PU7	0.08015860	VS1PU7I	0.	VS1PU8	0.05589480
VS1PU8I	0.	VS1PU9	0.03897560	VS1PU9I	0.
VS1PU	0.69730300	VT12	0.91007200	VTG1	0.99284800
VTG2	0.99414000	VTOP2	-0.22473400	VTREFG1	1.01000000
VTREFG2	1.01000000	VTRQGS2	0.	W42	87.2843000
W4R22	87.2843000	W542	97.4449000	W54R22	97.4449000
WAVE	4.00000000	WEFSEA	1.04720000	WESEA	0.08713720
WESEAMG	0.10000000	WESMAX	0.10000000	WFAC2	7671.22000
WFSR22	5848.37000	WFUEL2	7113.40000	WFUEL2I	2185.21000
WMG1D	-0.01753260	WMG2	369.589000	WMM1D	-2.01182000
WO	377.000000	WRN2ORD	1.00000000	WRN2ORDIC	1.00000000
WRNG1	0.99056400	WRNG2	0.98034400	WRNG2IC	1.00000000

WRNM1	0.66558600	WRNM2	0.66558600	XDC1	1.68000000
XDG1	1.63000000	XDG2	1.77000000	XDM1	1.76000000
XDMXQM1	0.60300000	XDPG1	0.25000000	XDPG2	0.18000000
XDPM1	0.60800000	XDPPG1	0.18000000	XDPPG2	0.15000000
XDPPM1	0.54200000	XG1	0.10000000	XG2	0.10000000
XK3L2	2.20000000	XL1	0.10000000	XLG1	0.07500000
XLG2	0.13000000	XLM1	0.33700000	XMV2	0.64105100
XQG1	1.01000000	XQG2	1.64000000	XQM1	1.15700000
XQPPG1	0.28000000	XQPPG2	0.15000000	XQPPM1	0.49400000
XVS0REF	207.220000	Z99885	0.45373000	Z99886	-1.15637000
Z99887	0.45370200	Z99888	0.45375400	Z99889	0.45374200
Z99891	1	Z99892	0.17226600	Z99893	-1.15052000
Z99894	0.17225600	Z99895	0.17227500	Z99896	0.17226700
Z99898	1	Z99899	0.92243400	Z99900	-0.72997400
Z99901	0.92492800	Z99902	0.92483600	Z99903	0.92487400
Z99905	1	Z99906	0.23362500	Z99907	-0.97512800
Z99908	0.23359000	Z99909	0.23366000	Z99910	0.23360400
Z99912	1	Z99920	0.08485850	Z99921	0.08485850
Z99945	7.00579000	Z99946	7.79347000	Z99949	3.02199000
Z99950	3.91157000	Z99960	47	Z99961	40
Z99962	55.4529000	Z99970	21	Z99971	61.0665000
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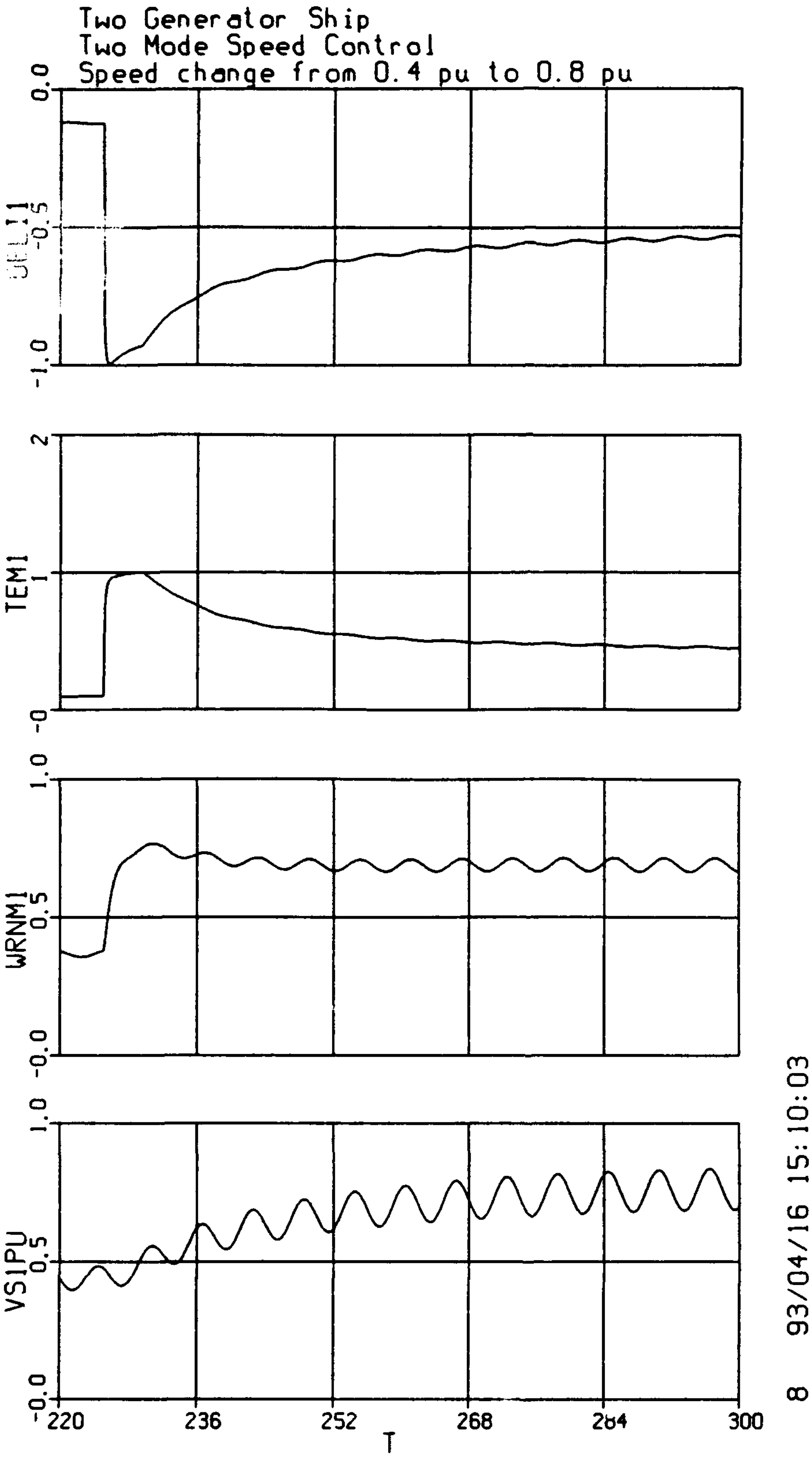
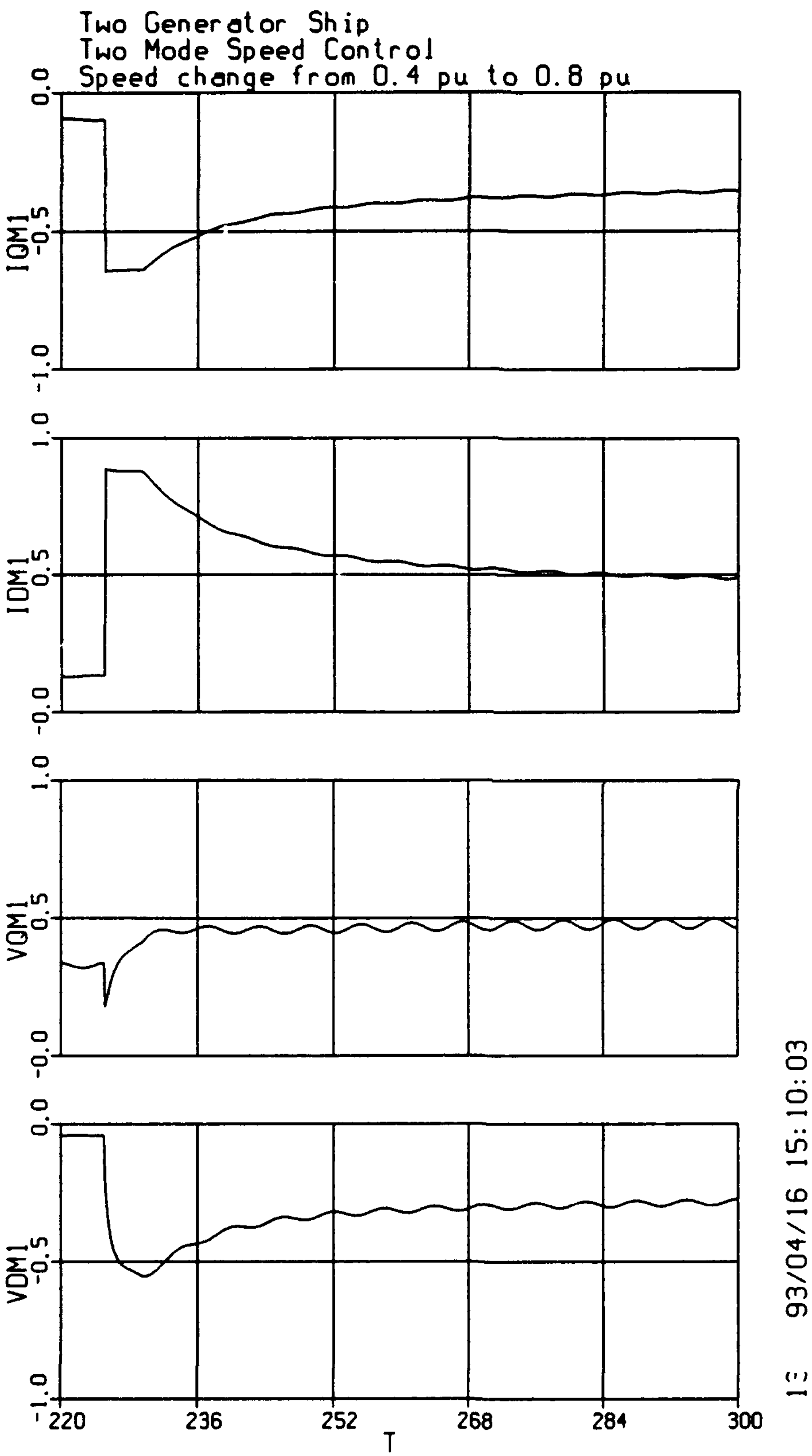


Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu
0.0
-0.5
-1.0
2
TEM1
1
-0
1.0
WRNM1
0.5
-0.0
1.0
VS1PU
0.5
-0.0
220
236
252
268
284
300
T
93/04/16 15:10:03
8


Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu
0.0
-0.5
-1.0
IQM1
1.0
0.5
-0.0
IDM1
1.0
0.5
-0.0
VQM1
0.0
-0.5
-1.0
VDM1
220
236
252
268
284
300
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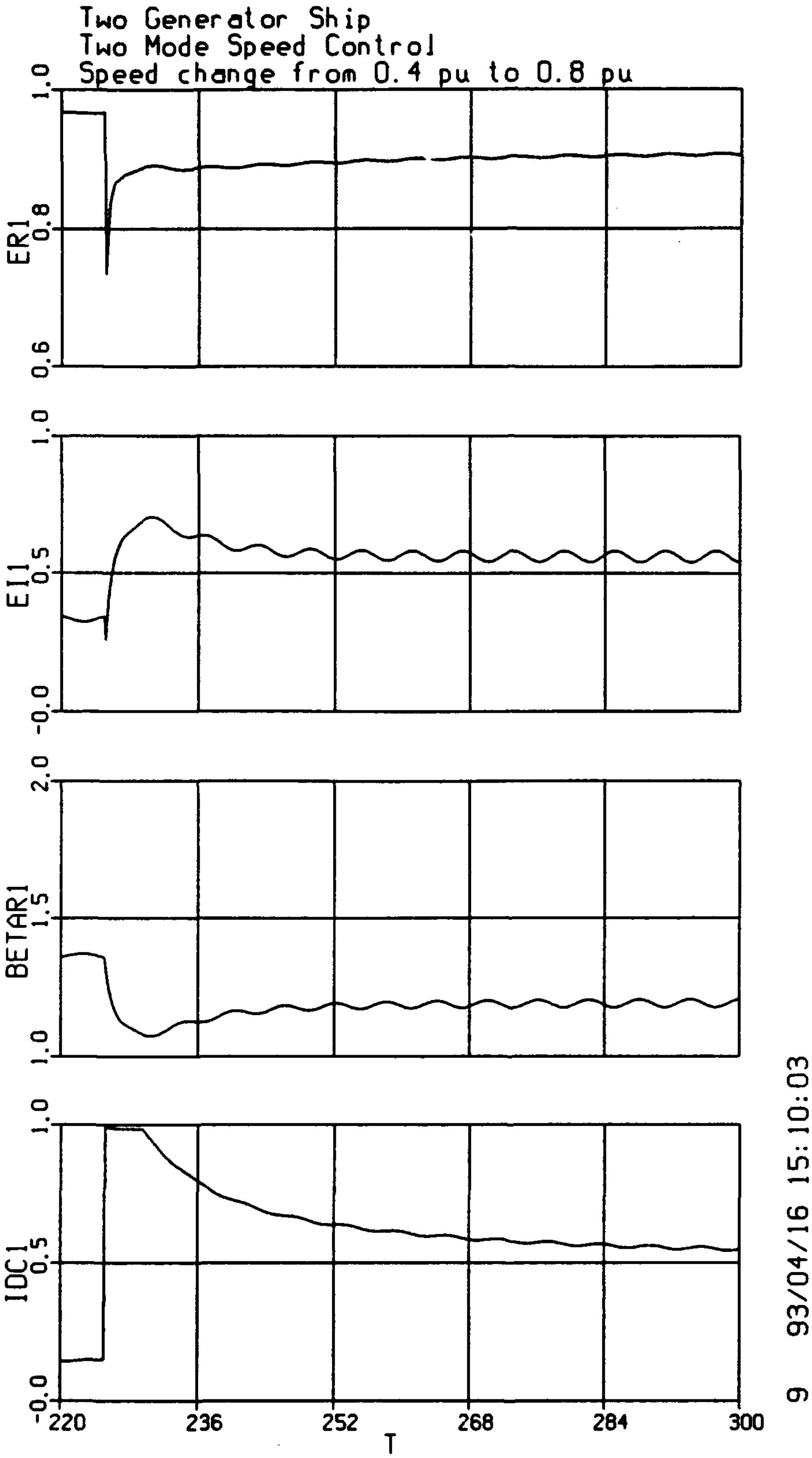
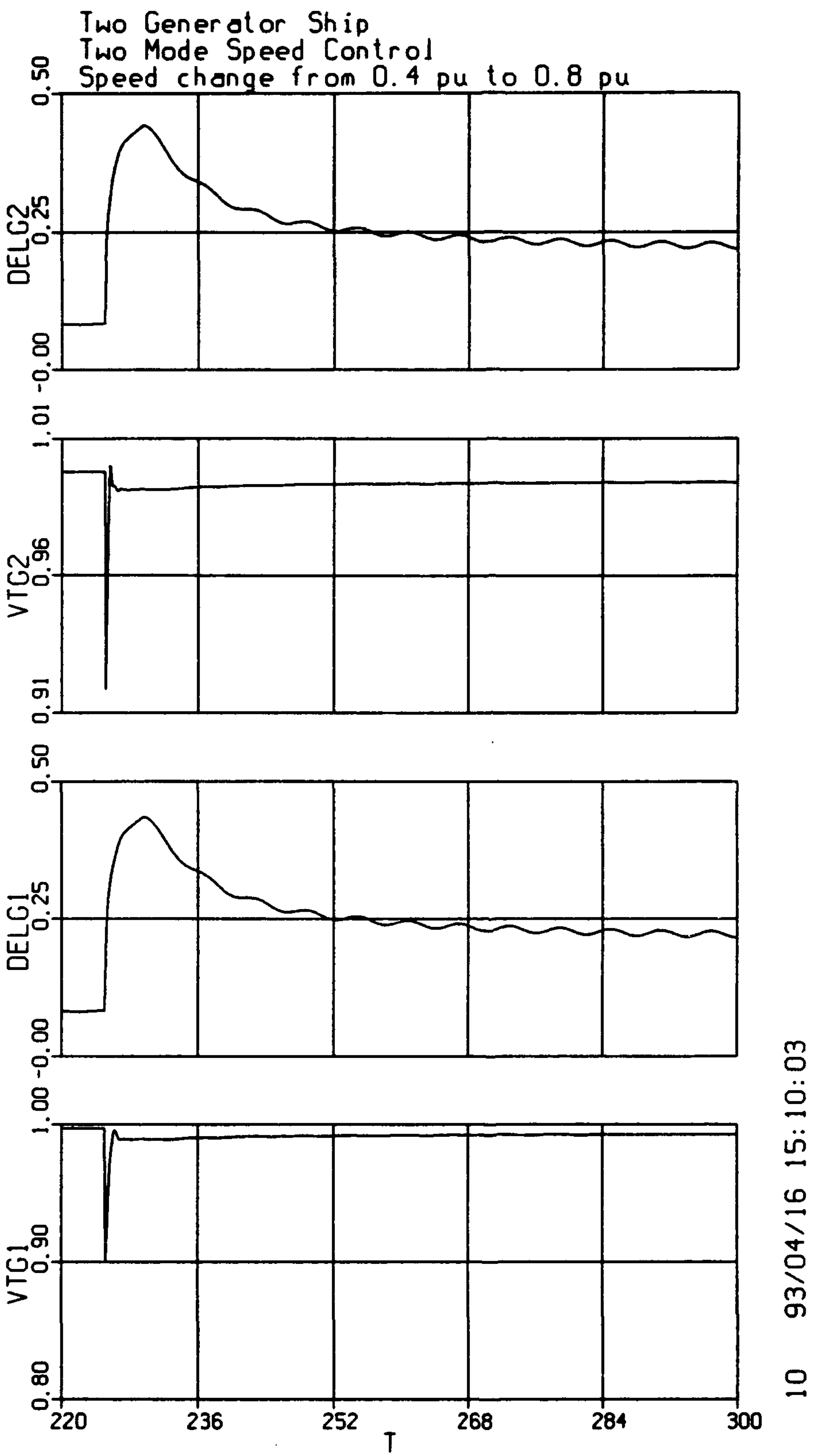
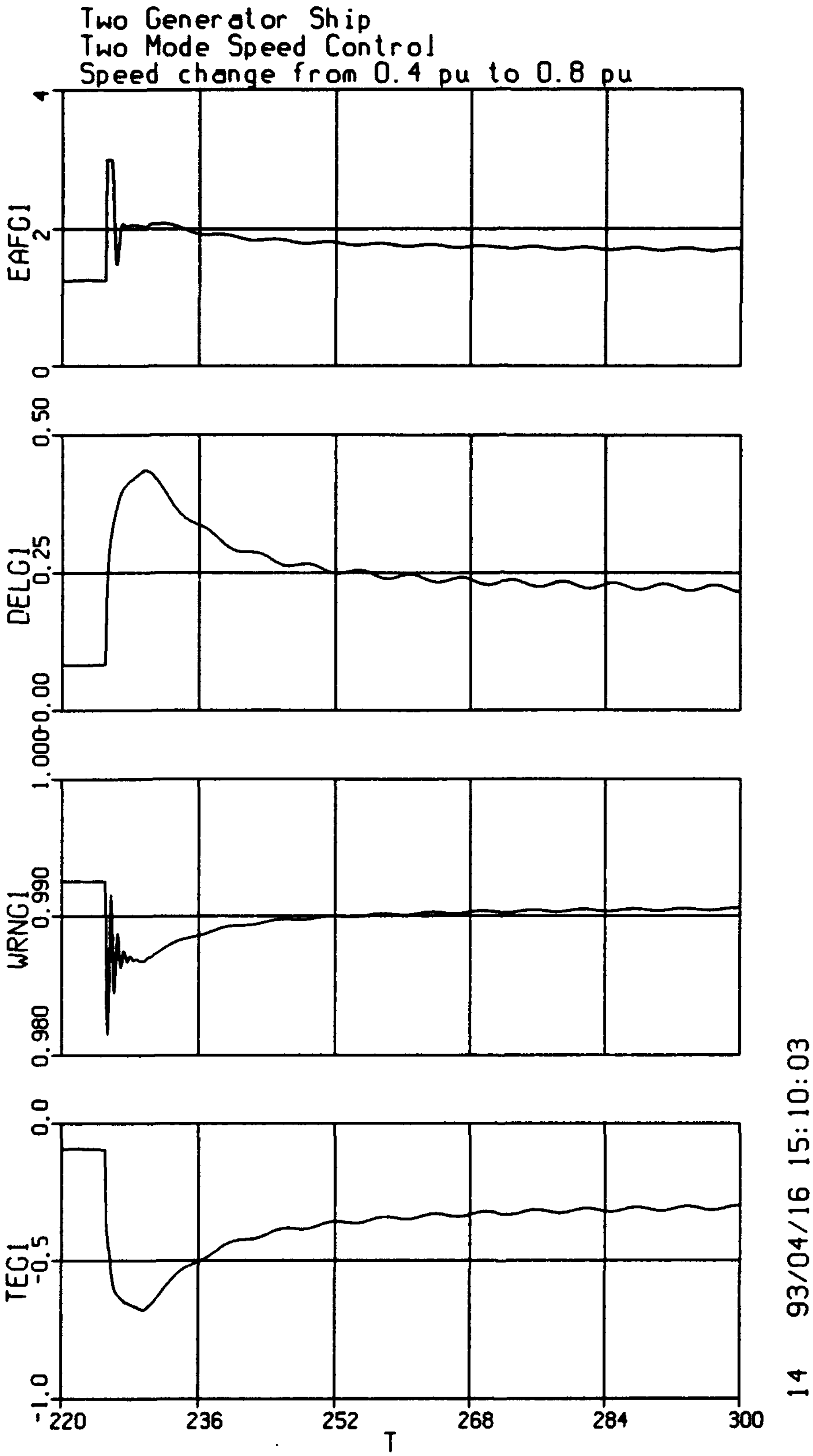
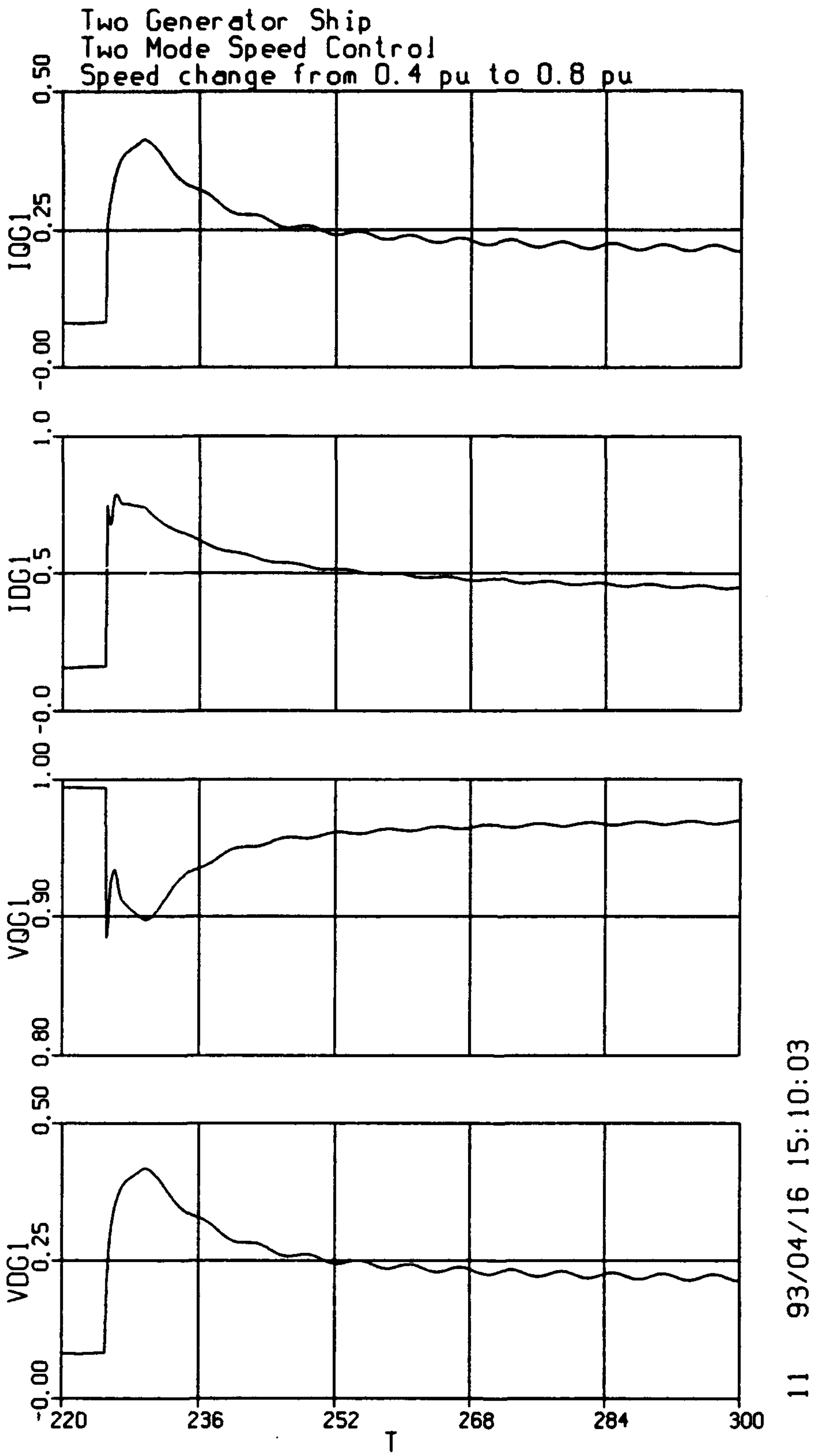
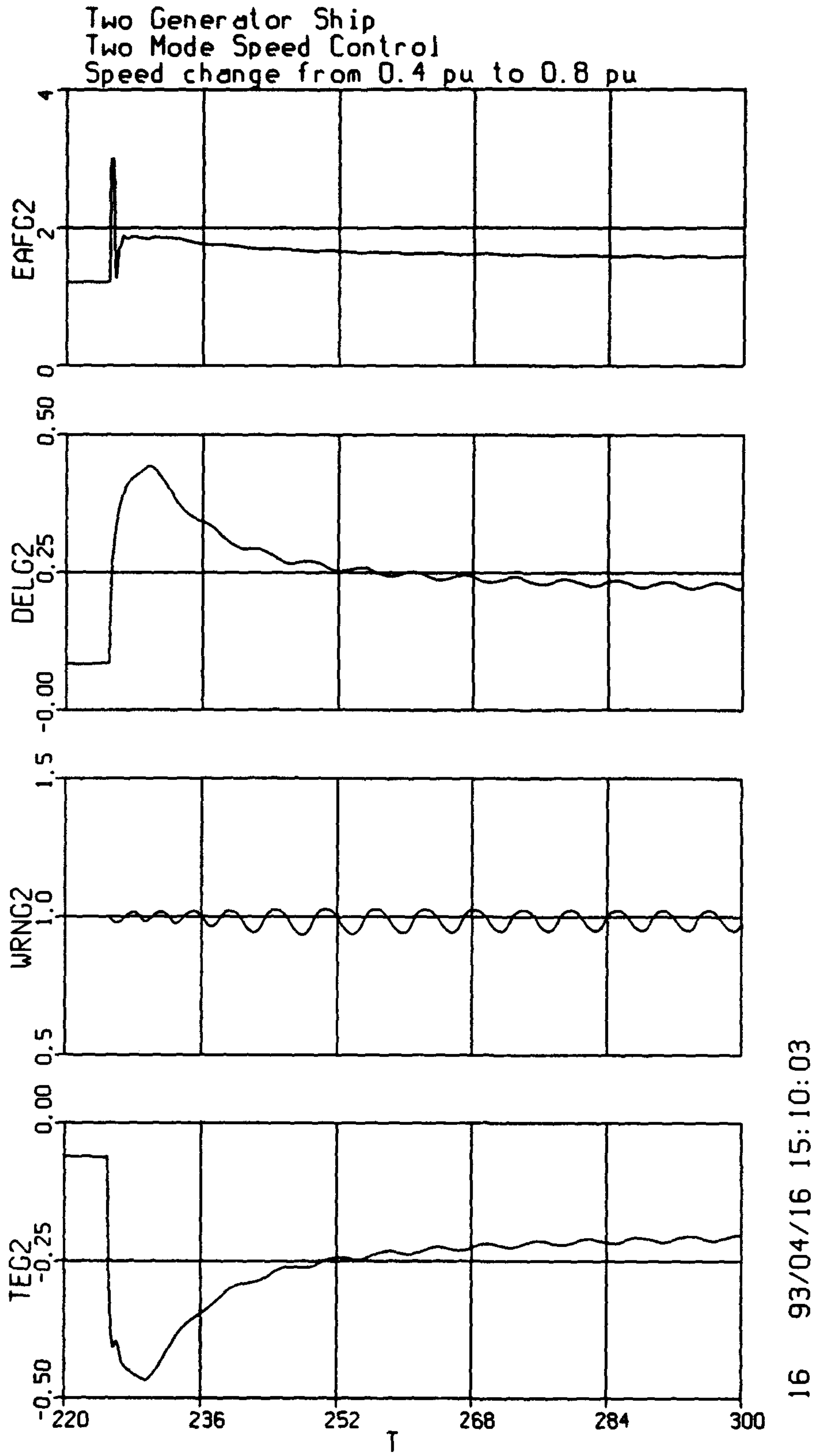
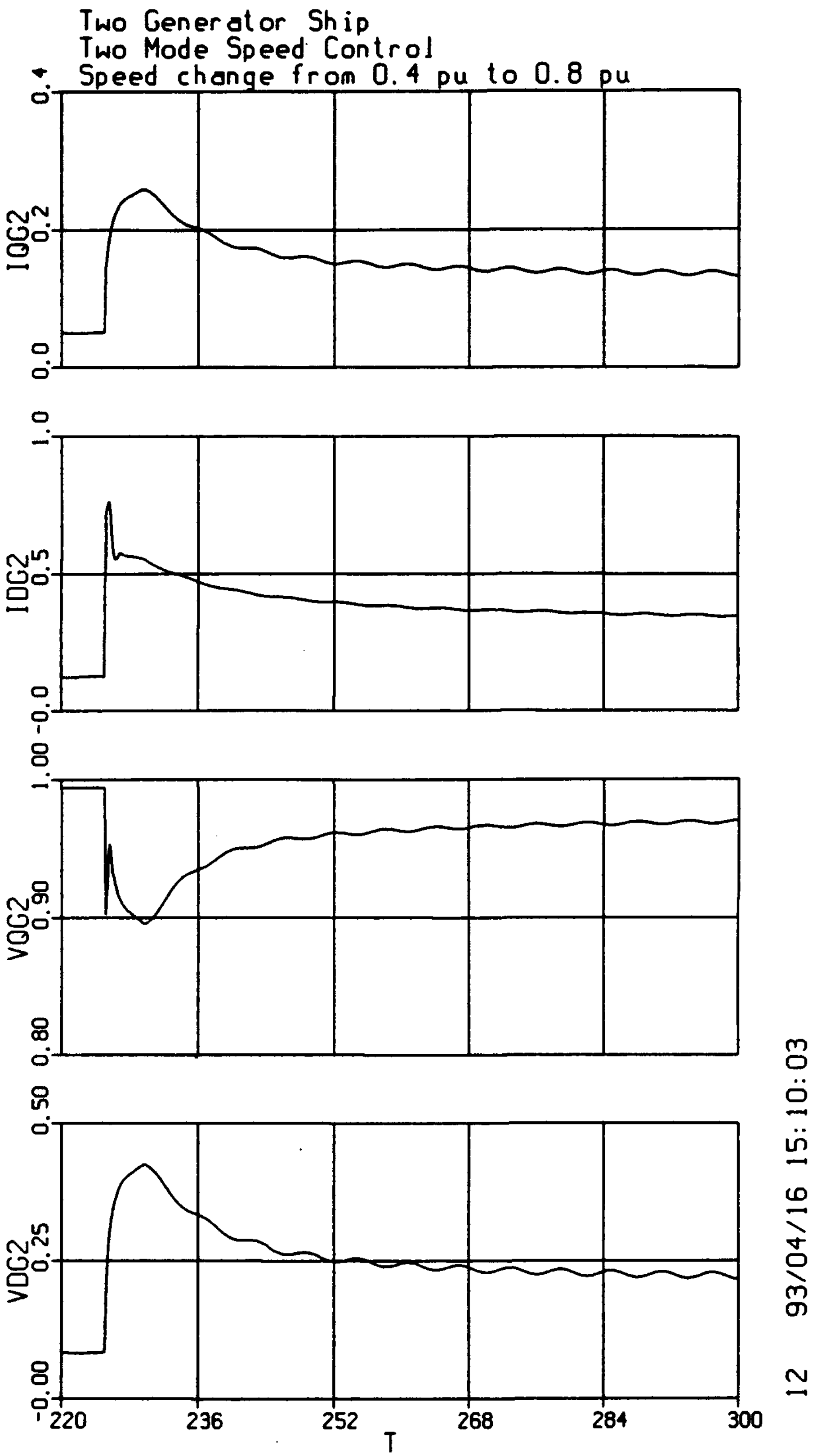

Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu
ER1
1.0
0.8
0.6
EI1
1.0
0.5
-0.0
BETAR1
2.0
1.5
1.0
IDC1
1.0
0.5
-0.0
220
236
252
268
284
300
T
93/04/16 15:10:03
9


Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu
DELG2
0.50
0.25
-0.00
VTG2
1.01
0.96
0.91
DELG1
0.50
0.25
-0.00
VTG1
1.00
0.90
0.80
220
236
252
268
284
300
T
93/04/16 15:10:03
10


Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu
EAFG1
DELG1
WRNG1
TEG1
4
2
0
0.50
0.25
0.00
1.000
0.990
0.980
0.0
-0.5
-1.0
220
236
252
268
284
300
T
93/04/16 15:10:03
14


Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu
IQG1
IDG1
VQG1
VDG1
0.50
0.25
-0.00
1.0
0.5
-0.0
1.00
0.90
0.80
220
236
252
268
284
300
T
93/04/16 15:10:03
11


Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu
EAFG2
4
2
0
DELG2
0.50
0.25
-0.00
WRNG2
1.5
1.0
0.5
TEG2
0.00
-0.25
-0.50
220
236
252
268
284
300
T
16 93/04/16 15:10:03


Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu
IQG2
0.0
0.2
0.4
IDG2
-0.0
0.5
1.0
VQG2
0.80
0.90
1.00
VDG2
-0.00
0.25
0.50
220
236
252
268
284
300
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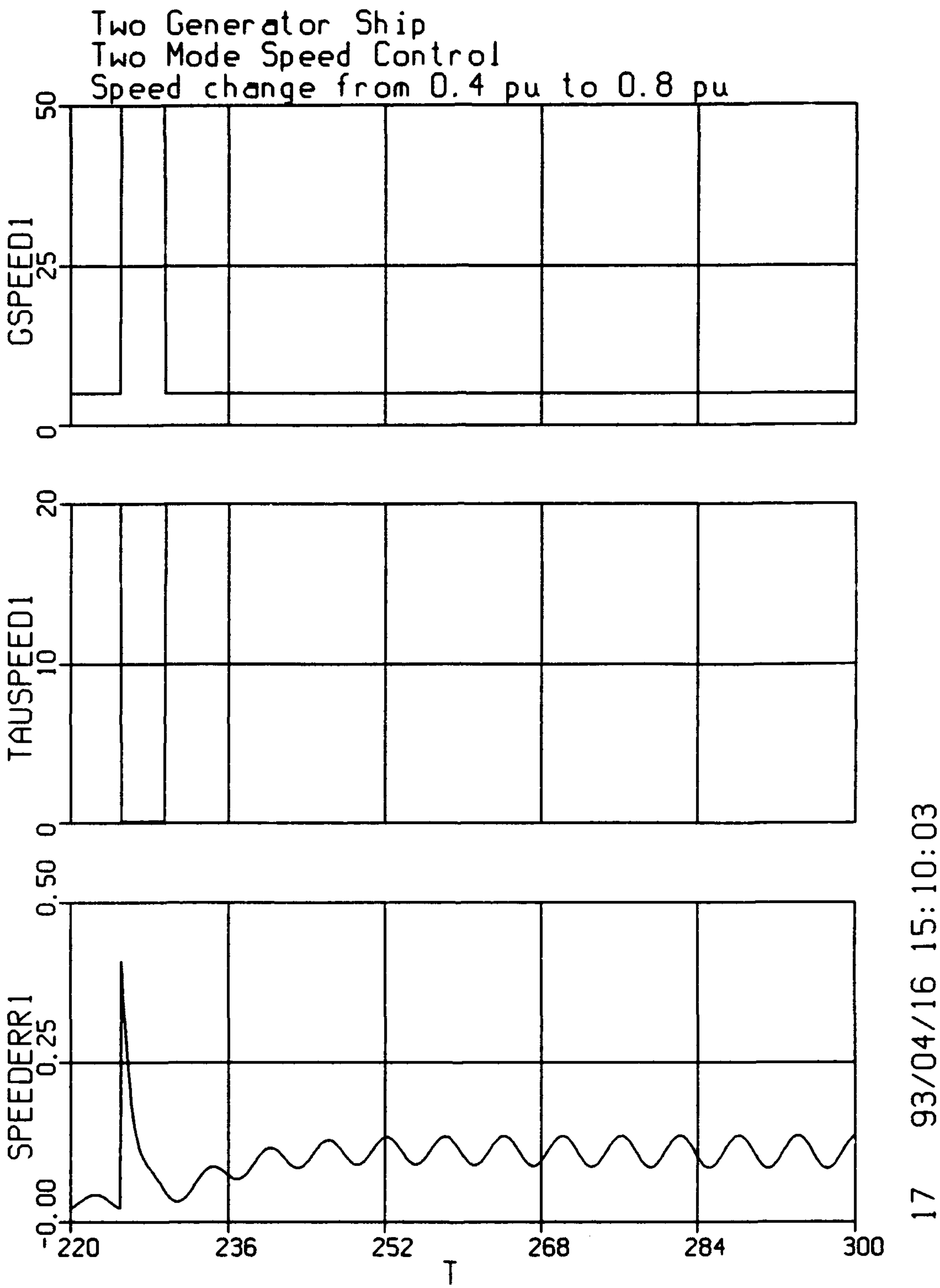
12



Two Generator Ship
Two Mode Speed Control
Speed change from 0.4 pu to 0.8 pu
GSPEED1
0
25
50
TAUSPEED1
0
10
20
SPEEDERR1
-0.00
0.25
0.50
220
236
252
268
284
300
T
93/04/16 15:10:03 17

D.5 Crashback

```
System #2:  Crashback with constant betai

      T 299.976000         ZZTICG 0.                  CINT 0.10000000
ZZIERR       F             ZZNBLK       1           ZZICON       0
ZZSTFL        T            ZZFRFL     F             ZZICFL    F
ZZRNFL       F             ZZJEFL     F             ZZNIST      40
ZZNAST          0            IALG       1             NSTP      10
  MAXT 0.10000000            MINT 1.0000E-08

tate Variables            Derivatives         Initial Conditions
  EDPPG1 0.09200280         Z99995-2.9785E-04      EDPPG1IC 0.
  EDPPG2 0.12685700         Z99992-3.8525E-04      EDPPG2IC 0.
  EDPPM1 0.10099800         Z99930-6.2064E-04      EDPPM1IC 0.
  ENPTL2 7.20000000         Z99942 0.               ENPTL2I 7.20000000
   EQPG1 1.03617000         Z99994-6.2035E-05       EQPG1IC 1.00000000
   EQPG2 1.03049000         Z99991-3.2982E-04       EQPG2IC 1.00000000
   EQPM1 1.18300000         Z99929-0.00118243       EQPM1IC 1.00000000
  EQPPG1 1.02296000         Z99996-1.0808E-04      EQPPG1IC 1.00000000
  EQPPG2 1.02307000         Z99993-1.7520E-04      EQPPG2IC 1.00000000
  EQPPM1 1.16925000         Z99931-0.00109473      EQPPM1IC 1.00000000
    IDC1 0.23447600         Z99922-0.00135037        IDC1IC 0.
    NGG2 7660.91000         Z99965-1.02656000         NGG2I 7193.84000
    NPT2 3600.00000         Z99978 0.00655201         NPT2I 3600.00000
   THMM1 4139.66000         Z99927-172.197000       THMM1IC 0.
  TICRL2 55.7481000         Z99959-0.03761290       TICRL2I 13.0000000
    WMG1 373.994000         Z99979 0.00208680        WMG1IC 377.000000
    WMM1-172.197000         Z99928-0.06058390        WMM1IC 0.
  Z99915 0.                 Z99914 0.                Z99913 0.
  Z99917-0.35474200         Z99916-0.00104634        VS1PUI 0.
  Z99919 0.24513500         Z99918-0.00144583       IDCR1IC 0.
  Z99924 0.31979300         Z99923-5.6624E-04          U1IC 0.99000000
  Z99926 1.42058000         Z99925 0.00810623       EAFM1IC 1.00000000
  Z99933 0.40957600         Z99932-2.5563E-04         XMV2I 0.31609000
  Z99935 7660.95000         Z99934-1.01318000        NGGL2I 7193.84000
  Z99937 98.2771000         Z99936-0.09670260        PS3WC2I 68.0631000
  Z99939-1.2782E-04         Z99938-1.1887E-04        EMFFB2I 0.
  Z99941 55.7940000         Z99940-0.03880470        ALPHA2I 40.9791000
  Z99944-345.140000         Z99943-4.0582E-05        TGLAG2I-345.140000
  Z99948-0.76408100         Z99947 0.00285566        TABTR2I 0.
  Z99952 577.409000         Z99951-2.03044000        QMAPL2I 0.
  Z99954 3600.00000         Z99953 0.00339084         NPTL2I 3600.00000
  Z99956 27.5043000         Z99955-0.01437390        P54LL2I 21.7097000
  Z99958 27.0973000         Z99957-0.01553130         P54L2I 21.3889000
  Z99964 1481.69000         Z99963-0.15346200        T51PL2I 1416.04000
  Z99967 2018.35000         Z99966-0.34237800         T4PL2I 1875.14000
  Z99973-0.11570300         Z99972-8.1380E-05         NERR2I 0.
  Z99981 0.14867200         Z99980-5.5449E-04      TMECH1IC 0.
  Z99986 1.00000000         Z99985 0.                FUEL1IC 0.
  Z99988 1.42252000         Z99987-0.01421450        EAFG2IC 1.00000000
  Z99990 1.29643000         Z99989 0.00253201        EAFG1IC 1.00000000
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Algebraic Variables

mon Block /ZZCOMU/

AFL2	0.17696700	AFRL2	0.17284600	ALPHA2	55.7940000
ALPHA2LL	13.0000000	ALPHA2UL	120.000000	ALPHAG1	20.7143000
ALPHAG2	54.0000000	ALPHAM1	18.4545000	ARLLG2I	0.31609000
BASEKWG1	2500.00000	BASEKWG2	16200.0000	BASEKWM1	14914.0000
BASENG1	900.000000	BASENG2	3600.00000	BASENM1	150.000000
BASEQM1	949455.000	BASEVG1	450.000000	BASEVG2	4160.00000
BASEVM1	5000.00000	BETAI1	2.20000000	BETAM1	2.20000000
BETAMINM1	1.57080000	BETAR1	1.24528000	CQLID2	2.8143E-05
CYL1	8.00000000	DELAY1	0.48568600	DELG1	0.12799800
DELG2	0.14067800	DELI1	-3.01265000	DELM1	-2.97629000
DELR1	0.16948800	DELTA2	1.00000000	DELV	1.0000E-04
DELVTQ2	0.	DELWF2	-2.65112000	DELWF2I	0.
DFL2	-0.75972300	DFRL2	-0.17233400	DN2	0.00655201
DNGG2	7660.70000	DNPT2	0.00655201	DNREF2	180.000000
DQ4S2	1.09706000	DQHR22	-2.99080000	DQPTR2	4690.85000
DRLLG2I	0.31609000	DRPMDT2	0.	DT4HS2	0.28814600
DT51HS2	0.26799100	DZ1	0.05000000	E02I	0.
E212	-0.00431820	E222	-0.25909200	E232	-0.08636400
E52	8.36484000	E62	0.	E72	0.14399800
E82	0.	E92	0.50000000	EAFERRM1	4.0531E-06
EAFG1	1.29643000	EAFG1D	0.00253201	EAFG2	1.42252000
EAFG2D	-0.01421450	EAFM1	1.42058000	EAFM1D	0.00810623
EAFM1MAX	3.00000000	EAFM1MIN	0.	EAFMAXG1	3.00000000
EAFMAXG2	3.00000000	EAFMING1	0.	EAFMING2	0.
EAFSM1	1.42059000	EDPPG1D	-2.9785E-04	EDPPG2D	-3.8525E-04
EDPPM1D	-6.2064E-04	EI1	0.50743000	EISM1	1.00000000
EMFFB2	-1.2782E-04	EMFSAT2	-1.6283E-05	ENGG2	-1.6283E-05
ENPT2	7.20000000	ENPT2I	7.20000000	EPM1	1.29454000
EQPG1D	-6.2035E-05	EQPG2D	-3.2982E-04	EQPM1D	-0.00118243
EQPPG1D	-1.0808E-04	EQPPG2D	-1.7520E-04	EQPPM1D	-0.00109473
ER1	0.94265500	ERRBOUND	1.0000E-04	ERX2	-1.6283E-05
FARG0	0	FARG1	1	FARG2	2
FARG3	3	FARGS0	0	FARGS1	1
FARGS2	2	FARGS3	3	FUEL1	0.21571000
FUEL1MAX	1.00000000	FUEL1MIN	0.	FUELAG1	0.05040080
G12	0.22000000	G32	0.50000000	G52	0.50000000
GBETAR1	30.0000000	GEAFG1	100.000000	GEAFG2	100.000000
GEAFM1	100.000000	GLARGE1	50.0000000	GM1	1.50000000
GSMALL1	5.00000000	GSPEED1	5.00000000	HG1	1.91000000
HG2	0.92400000	HHPS	0.51678100	HM1	1.28978000
HP2	2965.60000	HP2B	25000.0000	HP2D	2965.60000
HP2I	0.	HP2ORD	0.	HP2ORDI	0.
HPT2ORD	2965.60000	IAJXQM1	0.29913800	IAM1	0.25854600
ICLIM2	70.0000000	ICNTRL2	-0.11570300	ICNTRL2I	0.
ID2GR	1.00000000	IDBM1	0.	IDC1D	-0.00135037
IDCOM1	0.24513500	IDCR1	0.24513500	IDCR1D	-0.00144583
IDCR1DMAX	0.10000000	IDCR1DMIN	-0.10000000	IDCR1MAX	0.80000000
IDCR1MIN	0.	IDG1	0.18934800	IDG1IC	0.
IDG1M1	0.35266600	IDG2	0.24745800	IDG2ERR	0.
IDG2IC	0.	IDG2M1	0.32307100	IDI1	0.20903400
IDL2	0.18579900	IDM1	0.20903400	IDM1IC	0.
IDR1	0.24496900	IDXM1	0.12604700	IERR1	0.01065960

IERR1IC	0.	IGG2	566.778000	IITID2	580.484000
IQBM1	0.	IQG1	0.12595400	IQG1IC	0.
IQG1M1	0.23459300	IQG2	0.08511570	IQG2ERR	0.
IQG2IC	0.	IQG2M1	0.11112400	IQI1	0.15215500
IQL2	0.18035400	IQM1	0.15215500	IQM1IC	0.
IQR1	0.08268140	JJG	16505.0000	JJPROP	1.3130E+06
JJPS	1.4790E+06	JJPT2	2171.50000	JJSHFT	166000.000
K00RES	0.	K01RES	0.20233900	K02RES	-0.05737380
K03RES	0.96980600	K04RES	-0.23175100	K05RES	8.65721000
K06RES	-5.19908000	K07RES	-23.5963000	K08RES	15.9458000
K09RES	20.3595000	K10RES	-15.1637000	KALARM2	0
KBRAKE	1.00000000	KC12	0.50000000	KDFRQ	1.57080000
KGC	32.1740000	KGOV1	0.20000000	KHOLDPI2	1.00000000
KI	307.240000	KIG1M1	1.86253000	KIG2M1	1.30556000
KIR	2.00000000	KKWG1M1	0.16762800	KKWG2M1	1.08623000
KPNGG2	0.01017600	KQHP	5252.10000	KRAT2	0.16000000
KRATE2	10.0000000	KSHTDN2	0	KTBL2	0
KTURBO1	0.50000000	KVG1M1	0.09000000	KVG2M1	0.83200000
KVSHIP	0.00754970	KZG1M1	0.04832140	KZG2M1	0.63727300
LBRAKE	F	LDOPLR	F	LFWD1	F
LHEADR	F	LHOLD2PI	F	LNGG2A	F
LPWRD2	F	LSEA	F	LT542A	F
MAXIT	10.0000000	MFKAC2	0.58200000	MFKFR2	0.17259000
MFKMV2	23.0000000	MFKN2	4.6080E-08	MFW2	159.400000
	2091.30000		13659.6000	N1	892.843000
N2	3600.00000	N2I	3600.00000	NERR2	-4.8828E-04
NGB	3600.00000	NGG2B	9827.00000	NGGL2	7660.95000
NMAX1	950.000000	NMIN1	400.000000	NP1PU	-0.47342600
NP1PUI	5.3832E-06	NP1RPM	-68.5134000	NP1RPMI	7.7905E-04
NP2PU	-0.47342600	NP2PUI	5.3832E-06	NP2RMPI	7.7905E-04
NP2RPM	-68.5134000	NPRPMB	144.719000	NPRPSB	2.41200000
NPT2B	3600.00000	NPT2ORD	3600.00000	NPT2ORDI	3600.00000
NPT2R	3600.00000	NPT2RI	3600.00000	NPTL2	3600.00000
NPTQ2	158.068000	NPTQ2I	158.068000	NPTR2	3600.00000
NPTR2I	3600.00000	NREF2	3672.00000	NSET1	900.000000
P1	0.20000000	P2	14.6960000	P2T22	5.50753000
P542	27.0971000	P542I	21.3889000	P54L2	27.0973000
P54LL2	27.5043000	P54Q2	1.87155000	P54Q2I	1.47725000
P54R22	27.0946000	P54R22I	21.3889000	PAMB	14.6960000
PCNTRL2	-2.4414E-04	PCNTRL2I	0.	PCTID2	0.01000000
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PNGGR2	77.9578000	PNGGR2I	73.2049000	PS32	98.2732000
PS32I	68.0631000	PS3R22	98.2732000	PS3R22I	68.0631000
PS3WC2	98.2771000	PWRD2	11.8624000	PWRD2I	0.
Q1	0.15000000	Q42	7679.45000	Q4R22	7679.45000
QCAL2	3180.10000	QCAL2I	0.	QGB	36520.0000
QH2	-1.89374000	QLID2	364.730000	QLID2I	364.730000
QMAP2	577.348000	QMAP2I	0.	QMAPL2	577.409000
QP1	-244194.000	QP1F	-6229.08000	QP1FI	92443.6000
QP1I	-0.23332300	QP1PU	-0.19707800	QP1PUI	-1.8831E-07
QP2	-244194.000	QP2F	-6229.08000	QP2FI	92443.6000
QP2I	-0.23332300	QP2PU	-0.19707800	QP2PUI	-1.8831E-07
QPBASE	1.2391E+06	QPSBAF	92466.4000	QPT2	4691.69000
QPT2B	36473.0000	QPT2I	364.730000	QPT2PU	0.12846900
QREF2	45000.0000	RDC1	0.02000000	RS1PU0	0.00170916

RS1PU1-0.04231370	RS1PU2-0.05418350	RS1PU3-0.07177810
RS1PU-0.16656600	RS1PUI0 0.	RS1PUI1 0.
RS1PUI2 0.	RS1PUI3 0.	RS1PUI 0.
SEAFRQ 1.04720000	SEATIME 0.	SNEGVL2 0.
SPDERR1 7.15710000	SPDERR1IC 0.	SPDREF1-0.50000000
SPEEDERR1 0.04324370	SQRTH2 1.00000000	SWITCHVAR1 0.05578500
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T4P2 2017.02000	T4PL2 2018.35000	T4R22 2017.02000
T4U2-17.1120000	T512 1480.52000	T51P2 1480.25000
T51PL2 1481.69000	T51Q2 1.00018000	T51R22 1480.25000
T51U2-17.8027000	T542 971.106000	TABTR12 0.63516400
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TAUEAFG2 0.10000000	TAUEAFM1 0.05000000	TAUFAST1 0.10000000
TAUGOV1 2.00000000	TAUSLOW1 20.0000000	TAUSPEED1 20.0000000
TC12 3.00000000	TDOPG1 3.79000000	TDOPG2 3.19000000
TDOPM1 2.10000000	TDOPPG1 0.38000000	TDOPPG2 0.04000000
TDOPPM1 0.03900000	TDT542(48) 99999.0000	Z99968(36) 68.3000000
99969(12) 99999.0000	TEG1-0.14865100	TEG2-0.11847100
TEG2IC 0.	TEM1-0.19749300	TESM2 4326.57000
TESM2I 0.	TGLAG2 7.20000000	THDOT22-0.03768050
THET2N 1.00000000	THETA2 1.00000000	THRESHOLD1 0.10000000
THTA2V 1.00000000	TIC2 55.7444000	TIC2LL 13.0000000
TIC2UL 113.500000	TICMD2 55.7444000	TICMD2I 13.0000000
TICN2-0.11594700	TICN2I 0.	TICRL2LL-89.0000000
TICRL2UL 22.5000000	TICS2 55.8603000	TICS2I 13.0000000
TMAP(116) 950.000000	Z99997(96) 0.92280000	Z99998(20) 950.000000
TMG1 0.14867200	TMM1 0.19707800	TMM2 0.19707800
TORQ1 0.14840300	TP1PU-0.15258000	TP1PUI 0.
TP2PU-0.15258000	TP2PUI 0.	TQOPPG1 0.19000000
TQOPPG2 0.09000000	TQOPPM1 0.19300000	TSEA 6.00000000
TSTOP 300.000000	TURBOLAG1 0.43528500	TUT4H2 0.25857500
TUT51H2 0.10642200	TVS0REF 696.262000	U1 0.31979300
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VDBIC 0.	VDBUS 0.15073700	VDERR 0.
VDG1 0.12727000	VDG2 0.13962400	VDI1-0.06524800
VDM1-0.08046350	VDR1 0.15900500	VERRG1 0.01296680
VERRG2 0.01421100	VI1-0.49391900	VN2 7.34400000
VNSF2 500.000000	VQ2 9.00000000	VQBIC 1.00000000
VQBUS 0.95364400	VQERR 0.	VQG1 0.98887700
VQG2 0.98595200	VQI1-0.50321700	VQM1-0.48231400
VQR1 0.92914800	VQSF2 5000.00000	VR1 0.49860200
VR2 0.50000000	VRATE2 0.	VRSF2 360.000000
VS1PU0 1.0000E-05	VS1PU10 3.1559E-05	VS1PU10I 0.
VS1PU2 0.12584200	VS1PU2I 0.	VS1PU3-0.04464140
VS1PU3I 0.	VS1PU4 0.01583620	VS1PU4I 0.
VS1PU5-0.00561775	VS1PU5I 0.	VS1PU6 0.00199285
VS1PU6I 0.	VS1PU7-7.0695E-04	VS1PU7I 0.
VS1PU8 2.5078E-04	VS1PU8I 0.	VS1PU9-8.8964E-05
VS1PU9I 0.	VS1PU-0.35474200	VT12 0.93215900
VTG1 0.99703300	VTG2 0.99578900	VTM1 0.48898000
VTOP2 0.	VTREFG1 1.01000000	VTREFG2 1.01000000
VTRQGS2 0.	W42 59.3867000	W4R22 59.3867000
W542 66.4302000	W54R22 66.4302000	WAVE 4.00000000
WEFSEA 1.04720000	WESEA 0.	WESEAMG 0.

WESMAX	0.10000000	WFAC2	4480.39000	WFSR22	3308.34000
WFUEL2	3305.69000	WFUEL2I	2185.21000	WMG1D	0.00208680
WMG2	377.000000	WMM1D	-0.06058390	WO	377.000000
WRN2ORD	1.00000000	WRN2ORDIC	1.00000000	WRNG1	0.99202600
WRNG2	1.00000000	WRNG2IC	1.00000000	WRNM1	-0.45675600
WRNM2	-0.45675600	XDC1	1.68000000	XDG1	1.63000000
XDG2	1.77000000	XDM1	1.76000000	XDMXQM1	0.60300000
XDPG1	0.25000000	XDPG2	0.18000000	XDPM1	0.60800000
XDPPG1	0.18000000	XDPPG2	0.15000000	XDPPM1	0.54200000
XG1	0.10000000	XG2	0.10000000	XK3L2	2.20000000
XL1	0.10000000	XLG1	0.07500000	XLG2	0.13000000
XLM1	0.33700000	XM1	0.10000000	XMV2	0.40944900
XQG1	1.01000000	XQG2	1.64000000	XQM1	1.15700000
XQPPG1	0.28000000	XQPPG2	0.15000000	XQPPM1	0.49400000
XVSOREF	207.220000	Z99885	0.32307100	Z99886	-1.14391000
Z99887	0.32301700	Z99888	0.32311900	Z99889	0.32307100
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Z99898	1	Z99899	0.94822400	Z99900	-0.91074800
Z99901	0.95364500	Z99902	0.95354900	Z99903	0.95361000
Z99905	1	Z99906	0.15073700	Z99907	-1.17095000
Z99908	0.15071000	Z99909	0.15075900	Z99910	0.15072900
Z99912	1	Z99920	0.05578500	Z99921	0.05578500
Z99945	7.20000000	Z99946	7.20000000	Z99949	0.63602000
Z99950	0.63516400	Z99960	47	Z99961	40
Z99962	49.7148000	Z99970	21	Z99971	55.8603000
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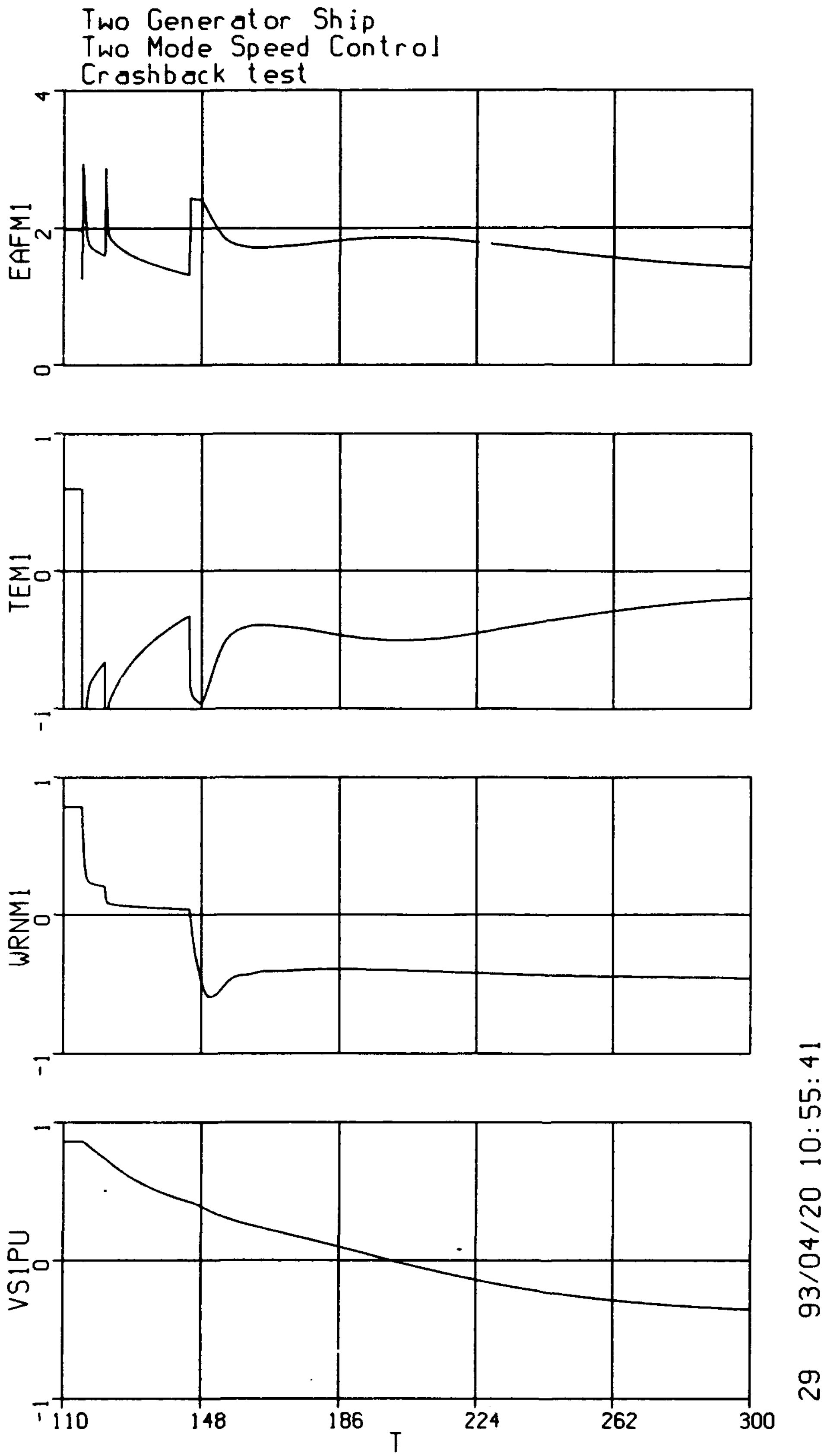

Two Generator Ship
Two Mode Speed Control
Crashback test
EAFM1
TEM1
WRNM1
VS1PU
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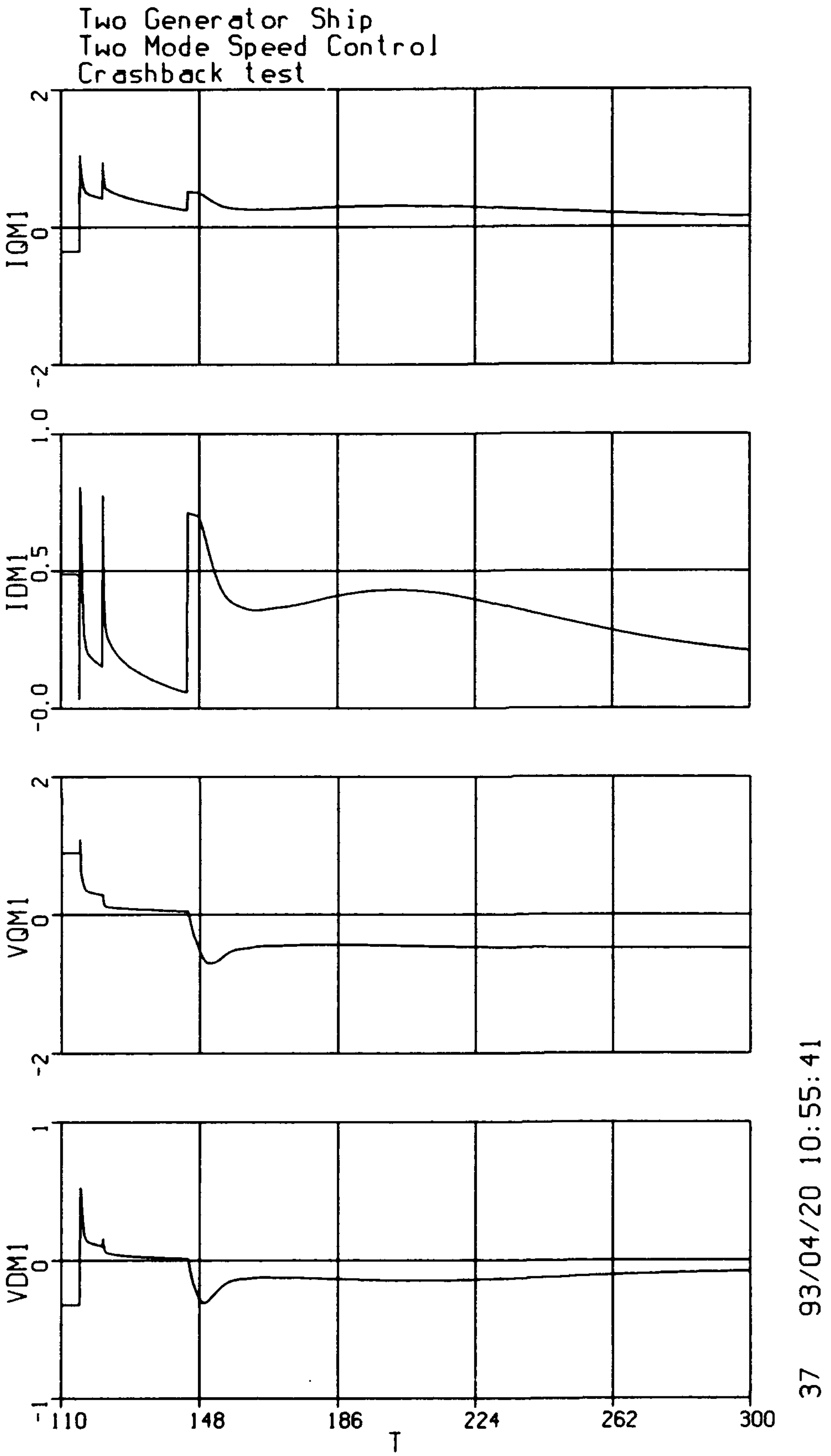
2
0
1
0
-1
110
148
186
224
262
300
T
29 93/04/20 10:55:41


Two Generator Ship
Two Mode Speed Control
Crashback test
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IDM1
VQM1
VDM1
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-0.0
1
-1
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148
186
224
262
300
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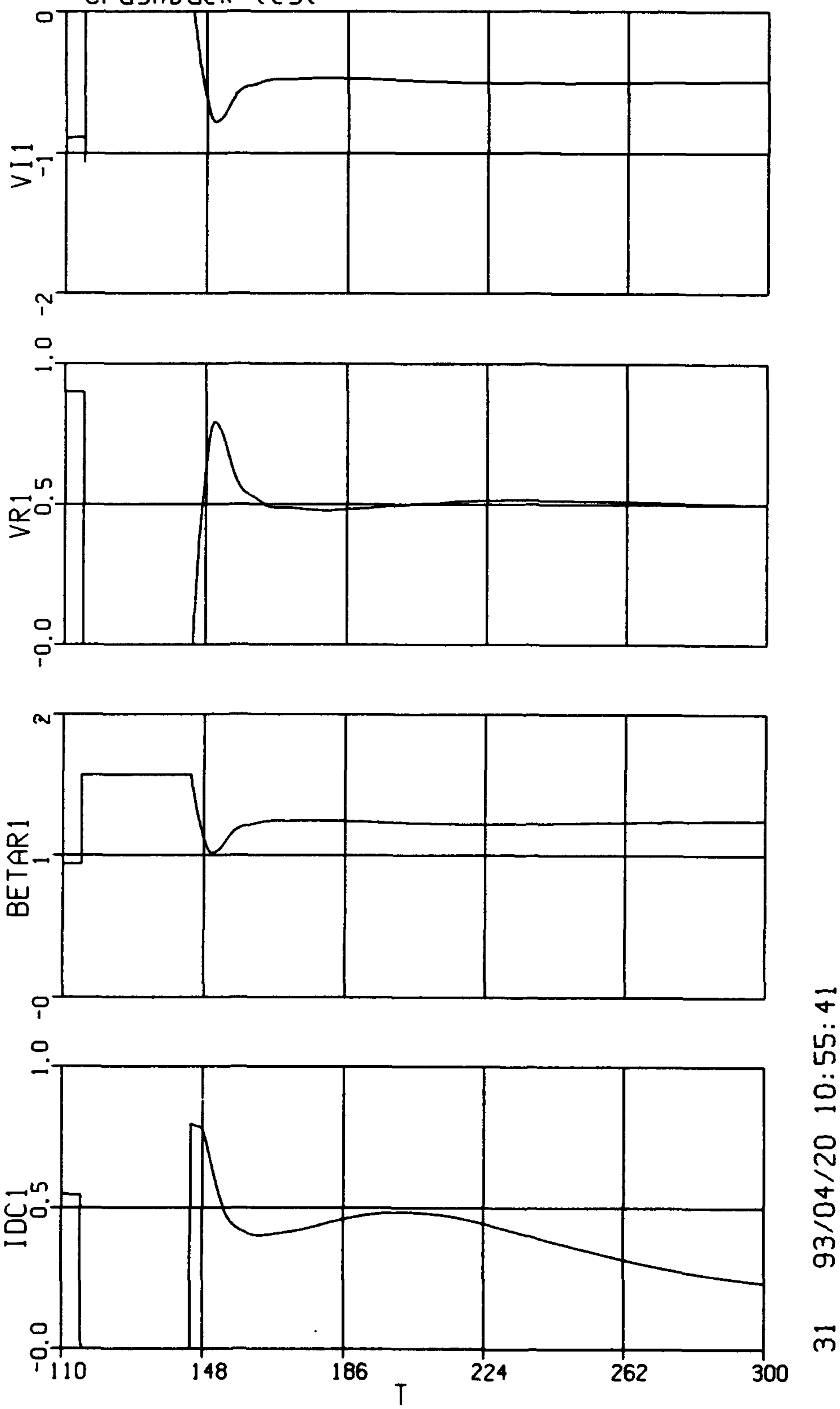
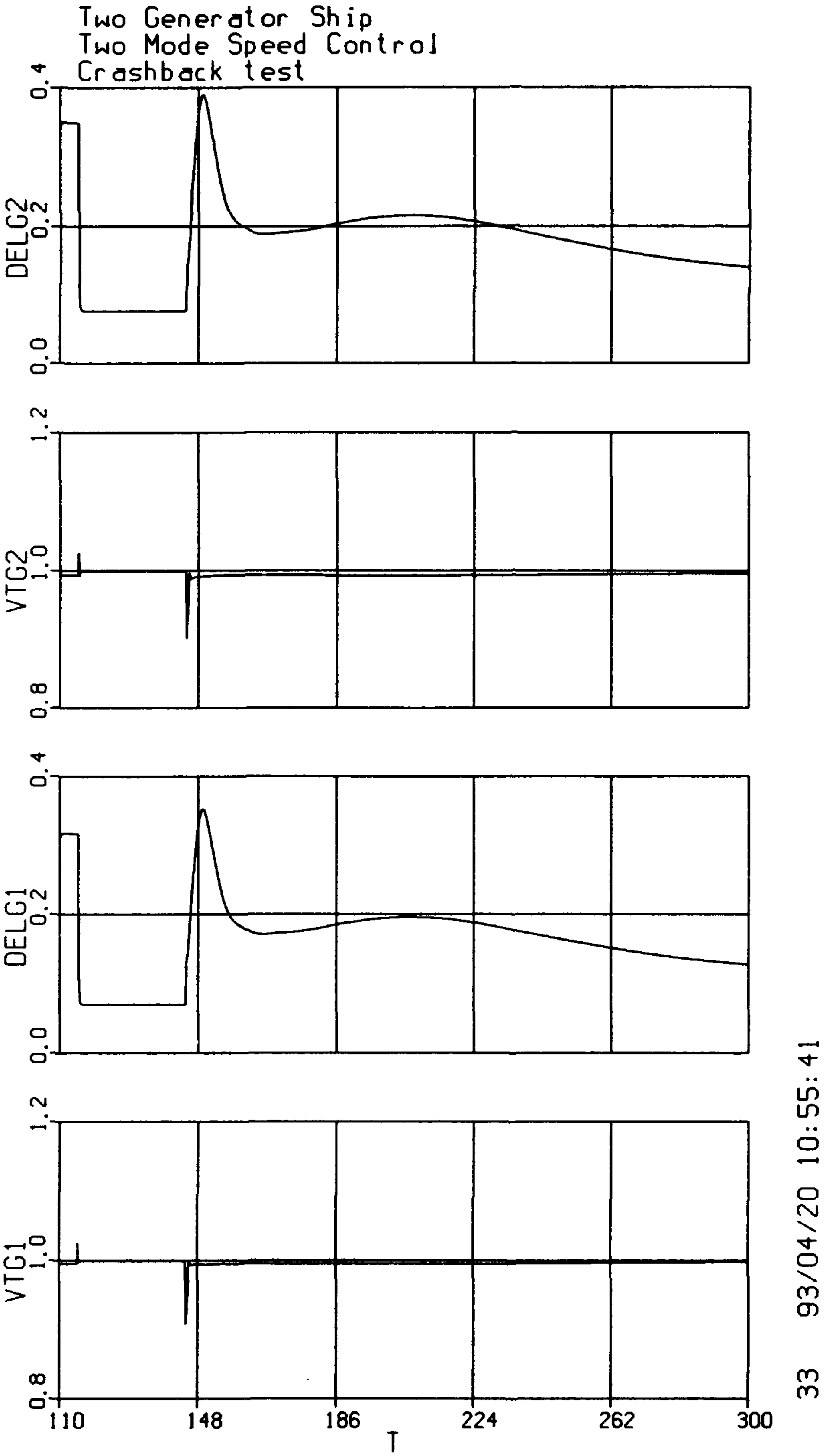
37

Two Generator Ship
Two Mode Speed Control
Crashback test





Two Generator Ship
Two Mode Speed Control
Crashback test
DELG2
VTG2
DELG1
VTG1
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1.0
1.2
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262
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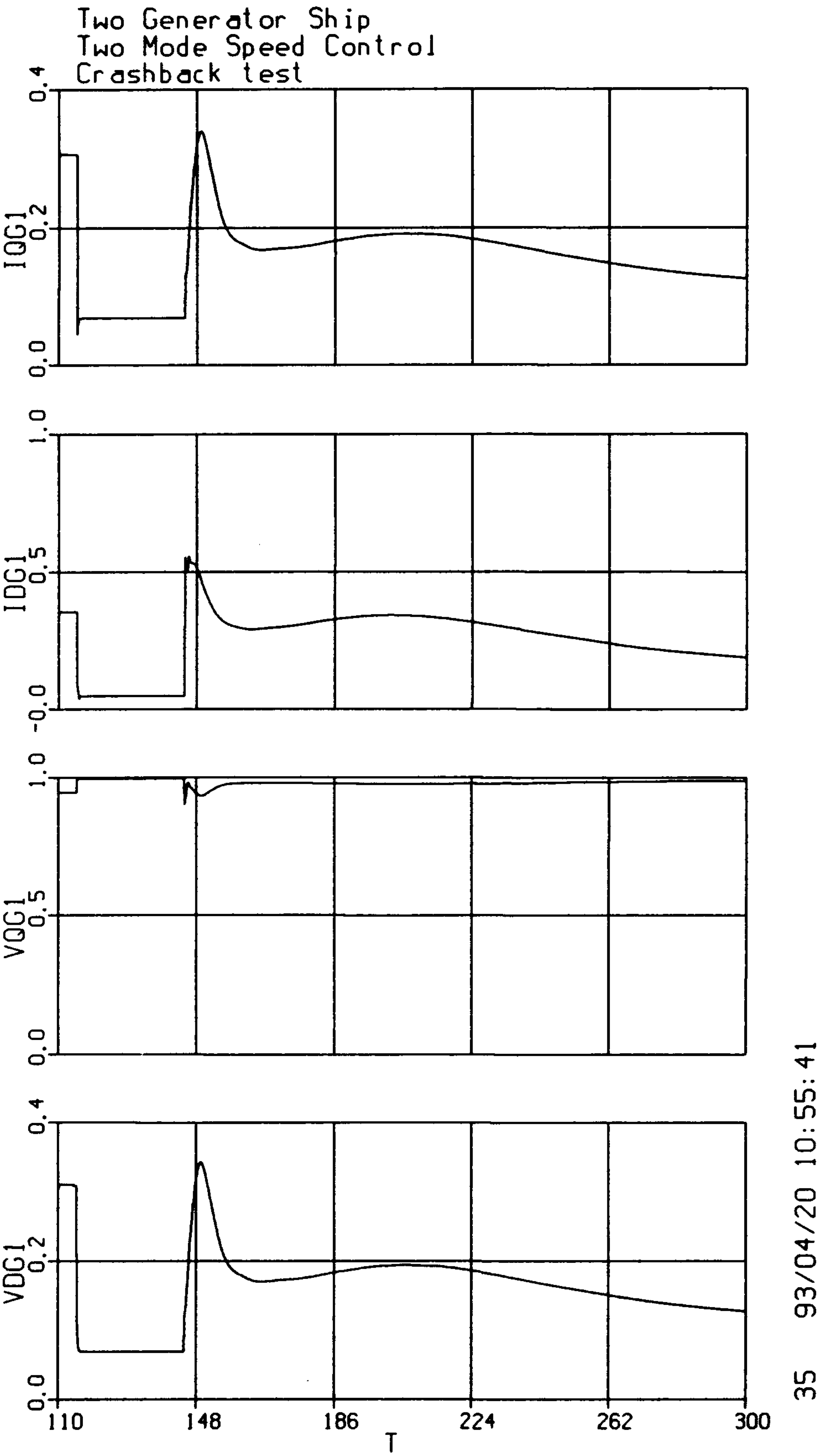
33



Two Generator Ship
Two Mode Speed Control
Crashback test
IQG1
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0.2
0.0
IDG1
1.0
0.5
-0.0
VQG1
1.0
0.5
0.0
VDG1
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0.2
0.0
110
148
186
224
262
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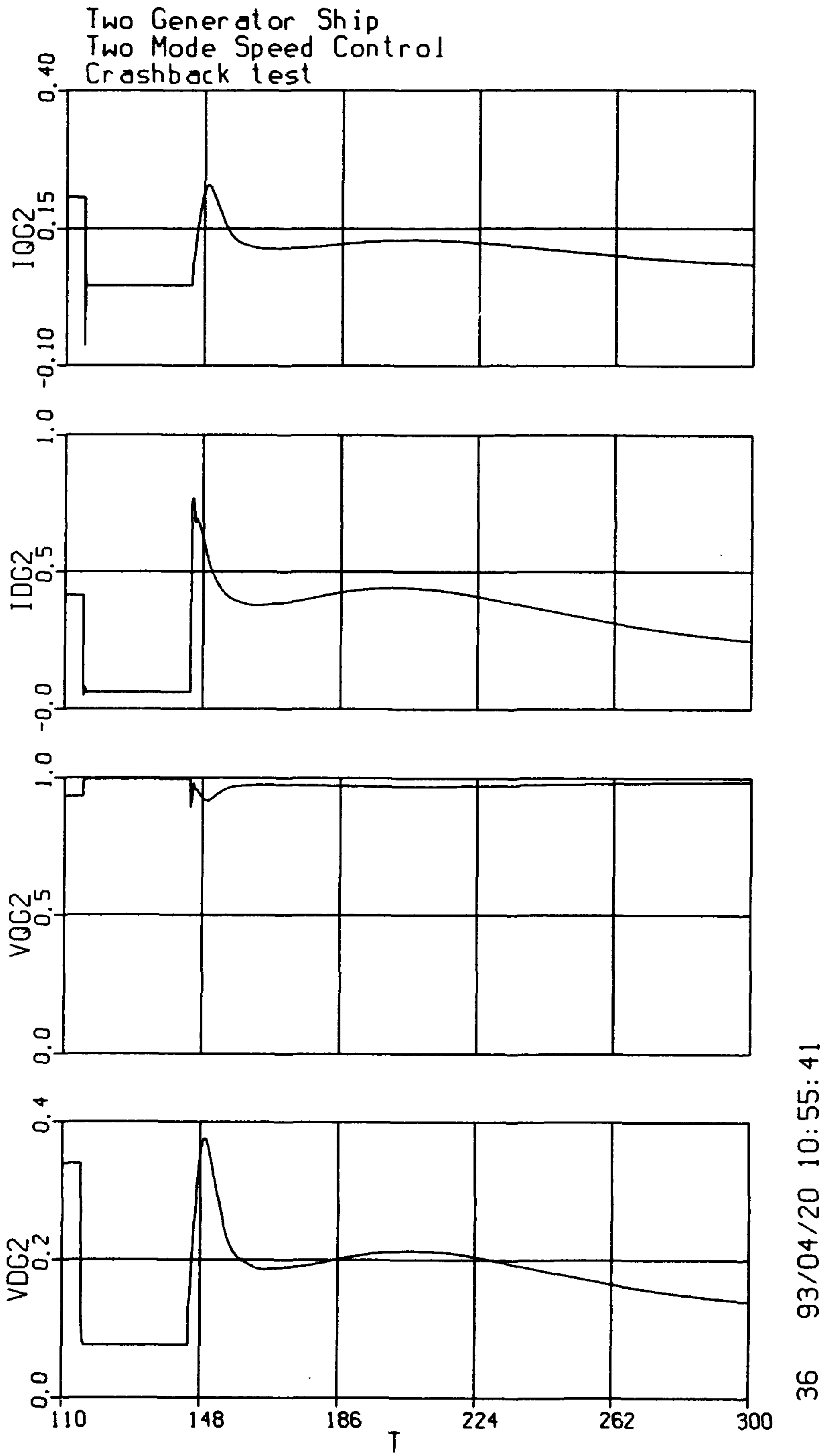
93/04/20 10:55:41
35



Two Generator Ship
Two Mode Speed Control
Crashback test
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0.15
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IDG2
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0.5
-0.0
VQG2
1.0
0.5
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VDG2
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0.2
0.0
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148
186
224
262
300
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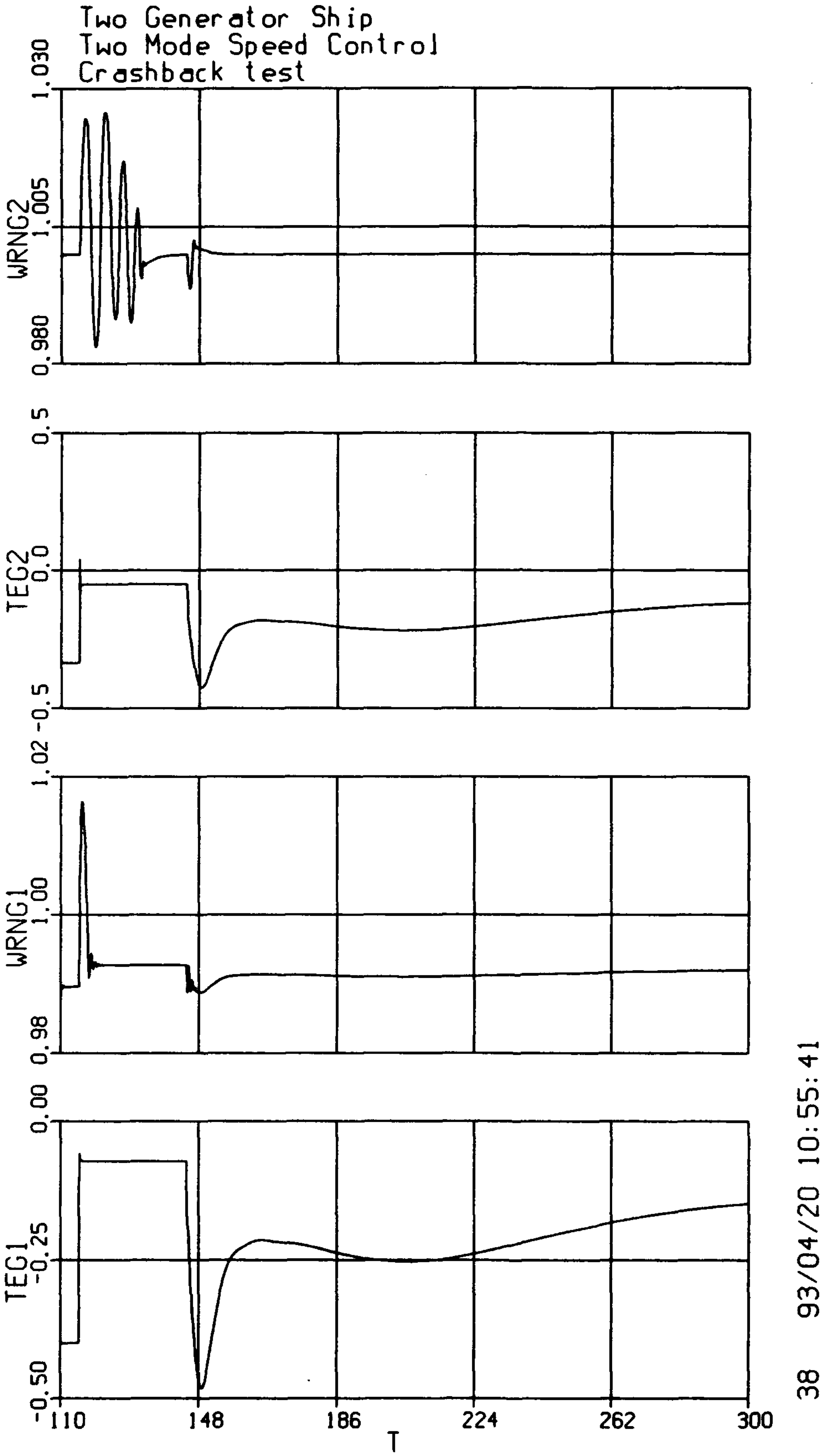
93/04/20 10:55:41
36


Two Generator Ship
Two Mode Speed Control
Crashback test
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1.005
0.980
TEG2
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0.0
-0.5
WRNG1
1.02
1.00
0.98
TEG1
0.00
-0.25
-0.50
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148
186
224
262
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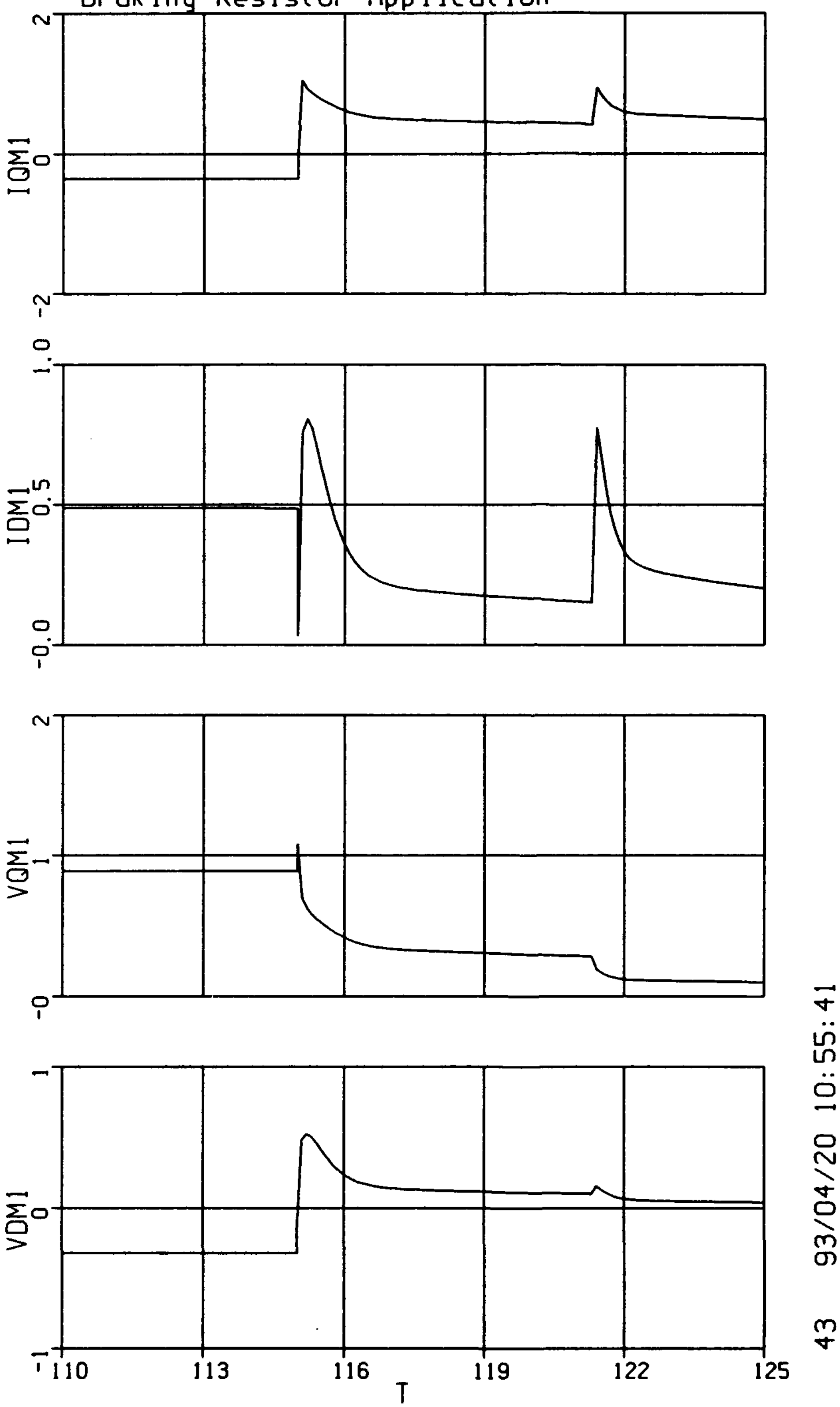
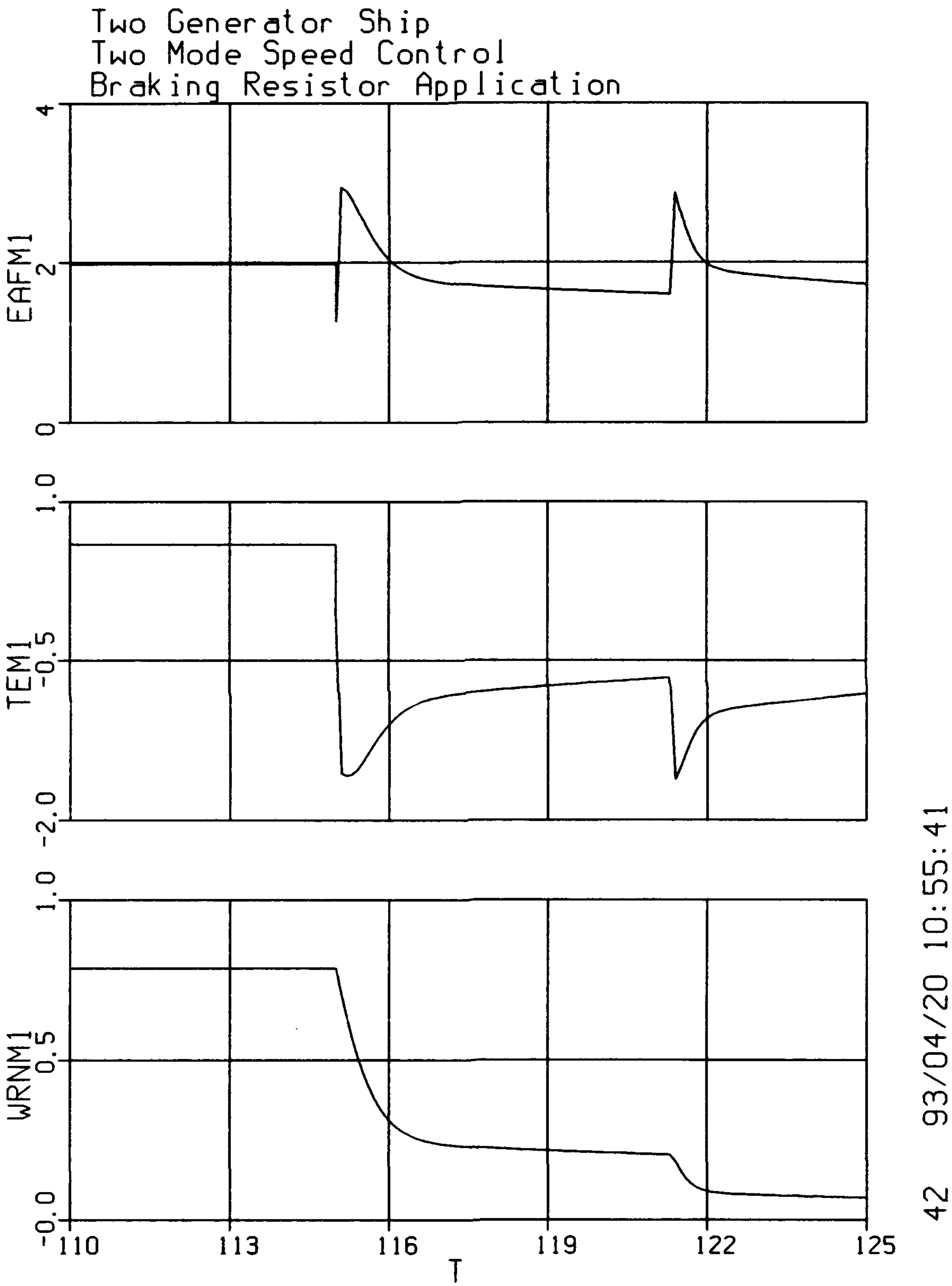
38

Two Generator Ship
Two Mode Speed Control
Braking Resistor Application




Two Generator Ship
Two Mode Speed Control
Braking Resistor Application
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WRNM1
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2
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1.0
-0.0
0.5
1.0
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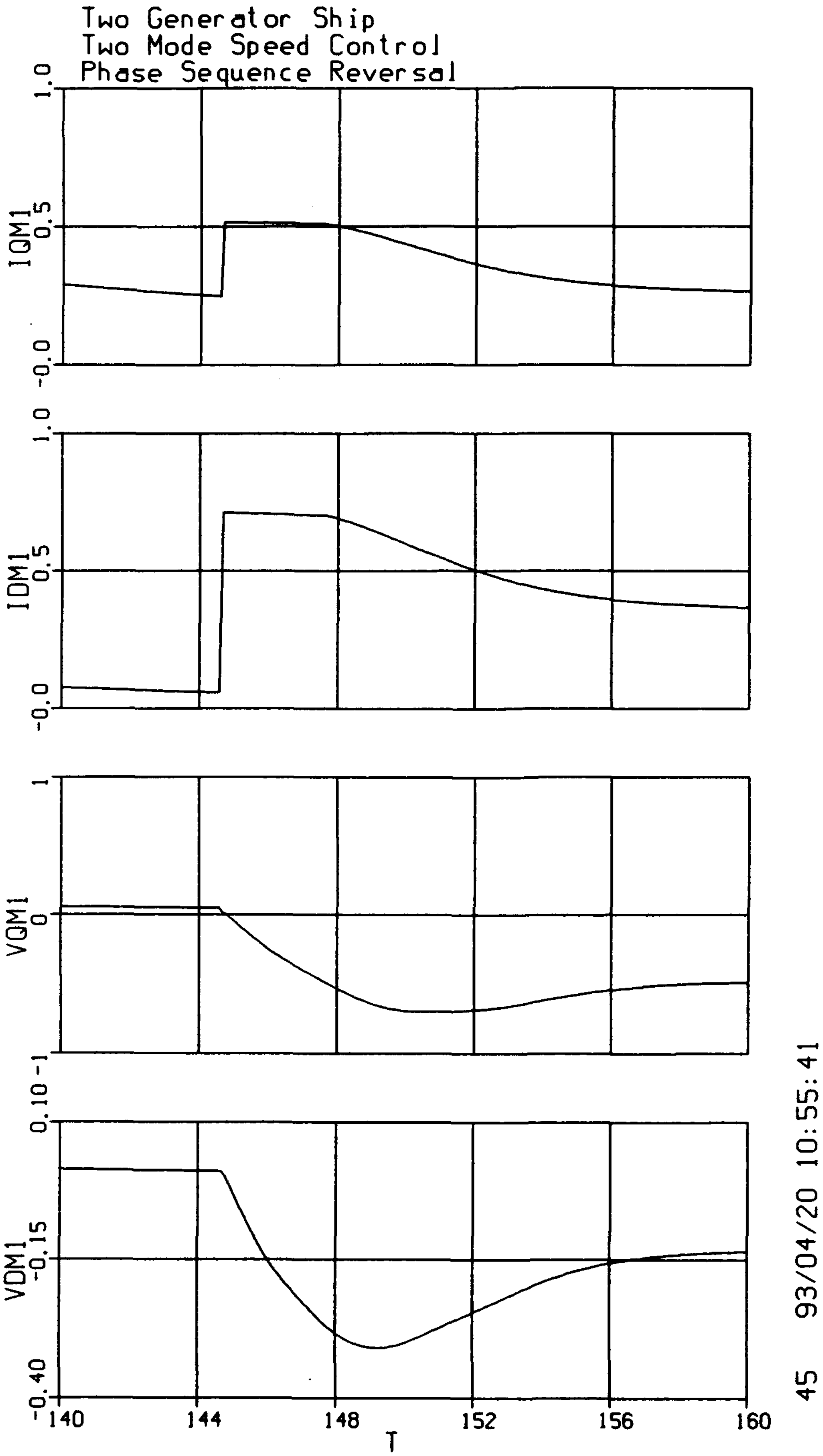
113
116
119
122
125
T
93/04/20 10:55:41
42


Two Generator Ship
Two Mode Speed Control
Phase Sequence Reversal
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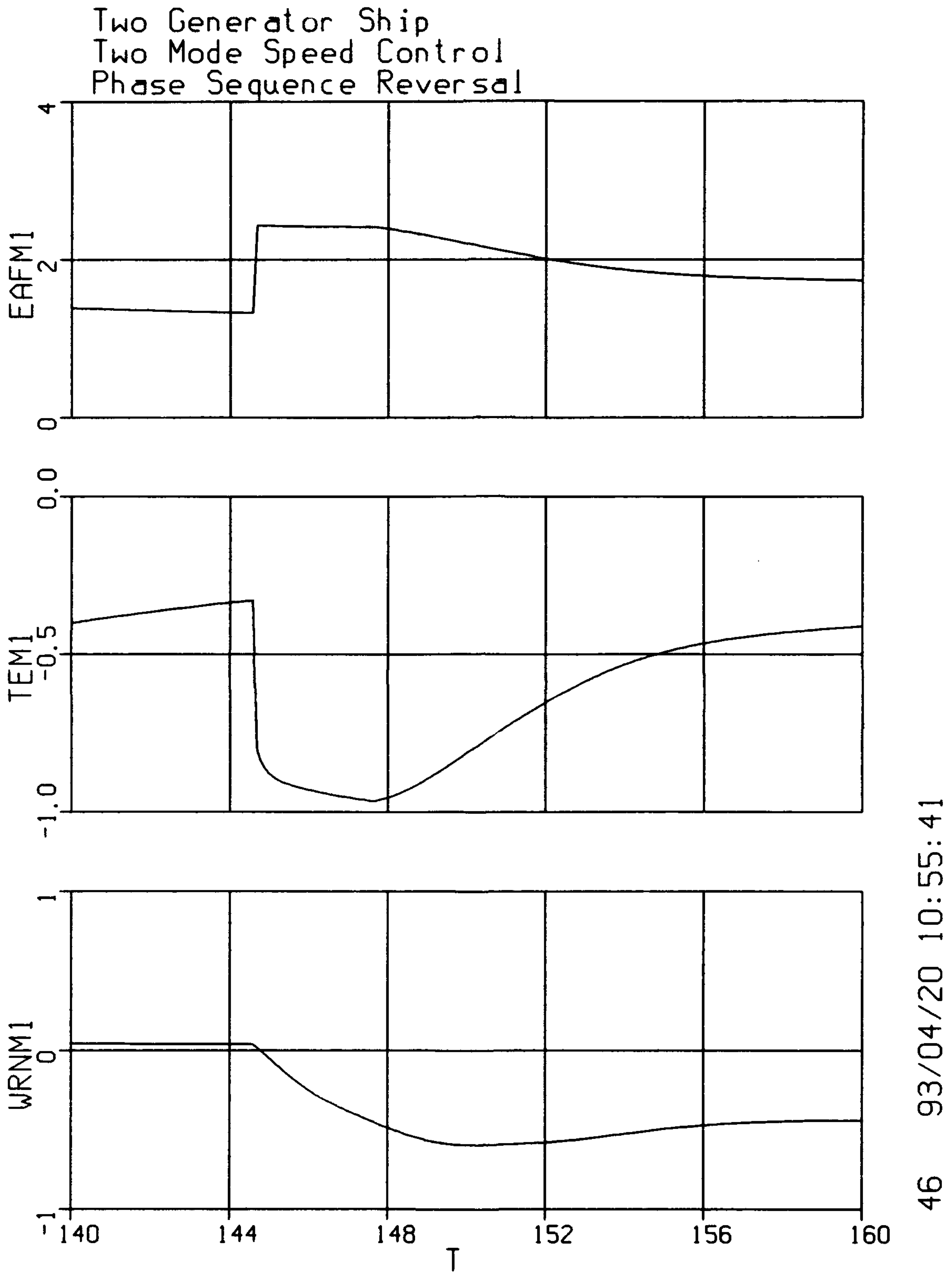
VQM1
VDM1
1.0
0.5
-0.0
1
0
-1
0.10
-0.15
-0.40
140
144
148
152
156
160
T
93/04/20 10:55:41 45


Two Generator Ship
Two Mode Speed Control
Phase Sequence Reversal
EAFM1
TEM1
WRNM1
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0.0
-0.5
-1.0
1
0
-1
140
144
148
152
156
160
T
93/04/20 10:55:41
46

D.6 Generator Failure at 50% Motor Speed

System #2a: Generator #2 failure at 50% ship speed

T	25.0000000	ZZTICG	0.	CINT	0.10000000
ZZIERR	F	ZZNBLK	1	ZZICON	0
ZZSTFL	T	ZZFRFL	F	ZZICFL	F
ZZRNFL	F	ZZJEFL	F	ZZNIST	40
ZZNAST	0	IALG	1	NSTP	10
MAXT	0.10000000	MINT	1.0000E-08		

tate Variables		Derivatives		Initial Conditions	
EDPPG1	0.29471100	Z99995	-1.0629E-04	EDPPG1IC	0.
EDPPG2	1.1644E-24	Z99992	-6.1282E-24	EDPPG2IC	0.
EDPPM1	-0.09589190	Z99930	8.4455E-05	EDPPM1IC	0.
ENPTL1	7.19898000	Z99942	-2.0266E-04	ENPTL1I	7.20000000
EQPG1	1.02696000	Z99994	-1.1006E-05	EQPG1IC	1.00000000
EQPG2	1.00000000	Z99991	-7.3017E-07	EQPG2IC	1.00000000
EQPM1	1.17125000	Z99929	-1.5063E-04	EQPM1IC	1.00000000
EQPPG1	1.01201000	Z99996	-2.2351E-06	EQPPG1IC	1.00000000
EQPPG2	1.00000000	Z99993	-7.8427E-07	EQPPG2IC	1.00000000
EQPPM1	1.15814000	Z99931	-1.4827E-04	EQPPM1IC	1.00000000
IDC1	0.22284700	Z99922	-1.7399E-04	IDC1IC	0.
NGG1	8081.00000	Z99965	-0.48811200	NGG1I	7193.84000
NPT1	3599.47000	Z99978	-0.05613670	NPT1I	3600.00000
THMM1	27350.3000	Z99927	171.236000	THMM1IC	0.
TICRL1	69.1367000	Z99959	0.11779800	TICRL1I	13.0000000
WMG2	380.807000	Z99979	1.4632E-07	WMG2IC	377.000000
WMM1	171.236000	Z99928	0.00998080	WMM1IC	0.
Z99915	0.	Z99914	0.	Z99913	0.
Z99917	0.51156600	Z99916	2.7909E-04	VS1PUI	0.
Z99919	0.23287300	Z99918	-1.9538E-04	IDCR1IC	0.
Z99924	0.30078100	Z99923	6.2585E-05	U1IC	0.99000000
Z99926	1.39970000	Z99925	-0.03814700	EAFM1IC	1.00000000
Z99933	0.52794400	Z99932	-3.6433E-04	XMV1I	0.31609000
Z99935	8081.02000	Z99934	-0.62255900	NGGL1I	7193.84000
Z99937	138.696000	Z99936	-0.02212520	PS3WC1I	68.0631000
Z99939	-1.8216E-04	Z99938	4.2240E-04	EMFFB1I	0.
Z99941	69.1148000	Z99940	0.	ALPHA1I	40.9791000
Z99944	-345.092000	Z99943	0.00927296	TGLAG1I	-345.140000
Z99948	-2.45794000	Z99947	0.00717958	TABTR1I	0.
Z99952	1857.90000	Z99951	-0.27262400	QMAPL1I	0.
Z99954	3599.49000	Z99953	-0.08816190	NPTL1I	3600.00000
Z99956	34.9975000	Z99955	-0.00118249	P54LL1I	21.7097000
Z99958	34.4802000	Z99957	0.	P54L1I	21.3889000
Z99964	1572.16000	Z99963	3.43217000	T51PL1I	1416.04000
Z99967	2214.47000	Z99966	1.81239000	T4PL1I	1875.14000
Z99973	-0.06887140	Z99972	0.08772790	NERR1I	0.
Z99981	1.4826E-09	Z99980	-2.6981E-09	TMECH2IC	0.
Z99986	1.00001000	Z99985	0.	FUEL2IC	0.
Z99988	0.99999100	Z99987	7.9870E-05	EAFG2IC	1.00000000
Z99990	1.81929000	Z99989	-7.5698E-04	EAFG1IC	1.00000000

Algebraic Variables

mon Block /ZZCOMU/

AFL1	0.14660200	AFRL1	0.17295400	ALPHA1	69.1148000
ALPHA1LL	13.0000000	ALPHA1UL	120.000000	ALPHAG1	54.0000000
ALPHAG2	20.7143000	ALPHAM1	18.4545000	ARLLG1I	0.31609000
BASEKWG1	16200.0000	BASEKWG2	2500.00000	BASEKWM1	14914.0000
BASENG1	3600.00000	BASENG2	900.000000	BASENM1	150.000000
BASEQM1	949455.000	BASEVG1	4160.00000	BASEVG2	450.000000
BASEVM1	5000.00000	BETAI1	2.20000000	BETAM1	2.20000000
BETAMINM1	1.57080000	BETAR1	1.26528000	CQLID1	2.8143E-05
CYL2	8.00000000	DELAY2	0.54949900	DELG1	0.33318900
DELG2	1.1644E-24	DELI1	-0.19531300	DELM1	-0.15796300
DELR1	0.39877300	DELTA2	1.00000000	DELV	1.0000E-04
DELVTQ1	0.	DELWF1	5.39990000	DELWF1I	0.
DFL1	-0.79008800	DFRL1	-0.17222600	DN1	-0.05613670
DNGG1	8080.75000	DNPT1	-0.05613670	DNREF1	180.000000
DQ4S1	-5.96718000	DQHR21	5.06674000	DQPTR1	13071.1000
DRLLG1I	0.31609000	DRPMDT1	-1.5240E-04	DT4HS1	-1.13085000
DT51HS1	-4.44555000	DZ1	0.05000000	E01I	0.
E211	0.00206329	E221	0.12379800	E231	0.04126580
E51	6.95567000	E61	0.	E71	0.14546300
E81	0.	E91	0.45832200	EAFERRM1	-1.9073E-05
EAFG1	1.81929000	EAFG1D	-7.5698E-04	EAFG2	0.99999100
EAFG2D	7.9870E-05	EAFM1	1.39970000	EAFM1D	-0.03814700
EAFM1MAX	3.00000000	EAFM1MIN	0.	EAFMAXG1	3.00000000
EAFMAXG2	3.00000000	EAFMING1	0.	EAFMING2	0.
EAFSM1	1.39968000	EDPPG1D	-1.0629E-04	EDPPG2D	-6.1282E-24
EDPPM1D	8.4455E-05	EI1	0.46612500	EISM1	1.00000000
EMFFB1	-1.8216E-04	EMFSAT1	2.5251E-06	ENGG1	2.5251E-06
ENPT1	7.19897000	ENPT1I	7.20000000	EPM1	1.27988000
EQPG1D	-1.1006E-05	EQPG2D	-7.3017E-07	EQPM1D	-1.5063E-04
EQPPG1D	-2.2351E-06	EQPPG2D	-7.8427E-07	EQPPM1D	-1.4827E-04
ER1	0.92096700	ERRBOUND	1.0000E-04	ERX1	2.5251E-06
FARG0	0	FARG1	1	FARG2	2
FARG3	3	FARGS0	0	FARGS1	1
FARGS2	2	FARGS3	3	FUEL2	0.
FUEL2MAX	1.00000000	FUEL2MIN	0.	FUELAG2	0.04949900
G11	0.22000000	G31	0.50000000	G51	0.50000000
GBETAR1	30.0000000	GEAFG1	100.000000	GEAFG2	100.000000
GEAFM1	100.000000	GLARGE1	50.0000000	GM1	1.50000000
GSMALL1	5.00000000	GSPEED1	5.00000000	HG1	0.92400000
HG2	1.91000000	HHPS	0.51678100	HM1	1.28978000
HP1	8685.66000	HP1B	25000.0000	HP1D	8685.66000
HP1I	0.	HP1ORD	0.	HP1ORDI	0.
HPT1ORD	8685.66000	IAJXQM1	0.28430200	IAM1	0.24572400
ICLIM1	70.0000000	ICNTRL1	-0.06887140	ICNTRL1I	0.
ID1GR	1.00000000	IDBM1	0.	IDC1D	-1.7399E-04
IDCBG2	0.	IDCOM1	0.23287300	IDCR1	0.23287300
IDCR1D	-1.9538E-04	IDCR1DMAX	5.00000000	IDCR1DMIN	-5.00000000
IDCR1MAX	0.80000000	IDCR1MIN	0.	IDG1	0.49834100
IDG1IC	0.	IDG1M1	0.65061600	IDG2	0.
IDG2ERR	0.	IDG2IC	0.	IDG2M1	0.
IDI1	0.19866700	IDL2	0.18192500	IDM1	0.19866700
IDM1IC	0.	IDR1	0.23434500	IDXM1	0.11979600

IERR1	0.01002610	IERR1IC	0.	IGG1	566.778000
IITID1	580.484000	IQBM1	0.	IQCBG2	0.
IQG1	0.19778600	IQG1IC	0.	IQG1M1	0.25822200
IQG2	0.	IQG2ERR	0.	IQG2IC	0.
IQG2M1	0.	IQI1	-0.14460900	IQL2	0.11040400
IQM1	-0.14460900	IQM1IC	0.	IQR1	0.07390910
JJG	16505.0000	JJPROP	1.3130E+06	JJPS	1.4790E+06
JJPT1	2171.50000	JJSHFT	166000.000	K00RES	0.
K01RES	0.20233900	K02RES	-0.05737380	K03RES	0.96980600
K04RES	-0.23175100	K05RES	8.65721000	K06RES	-5.19908000
K07RES	-23.5963000	K08RES	15.9458000	K09RES	20.3595000
K10RES	-15.1637000	KALARM1	0	KBRAKE	1.00000000
KC11	0.50000000	KDFRQ	1.57080000	KGC	32.1740000
KGOV2	0.20000000	KHOLDPI1	1.00000000	KI	307.240000
KIG1M1	1.30556000	KIG2M1	1.86253000	KIR	2.00000000
KKWG1M1	1.08623000	KKWG2M1	0.16762800	KPNGG1	0.01017600
KQHP	5252.10000	KRAT1	0.16000000	KRATE1	10.0000000
KSHTDN1	0	KTBL1	0	KTURBO2	0.50000000
KVG1M1	0.83200000	KVG2M1	0.09000000	KVSHIP	0.00754970
KZG1M1	0.63727300	KZG2M1	0.04832140	LBRAKE	F
LCBG2	F	LDOPLR	F	LFWD1	T
LHEADR	F	LHOLD1PI	F	LNGG1A	F
LPWRD1	F	LSEA	F	LT541A	F
MAXIT	10.0000000	MFKAC1	0.58200000	MFKFR1	0.17259000
MFKMV1	23.0000000	MFKN1	4.6080E-08	MFW1	159.400000
	2091.30000		13659.6000	N1	3599.47000
N1I	3600.00000	N2	909.109000	NERR1	0.52636700
NGB	3600.00000	NGG1B	9827.00000	NGGL1	8081.02000
NMAX2	950.000000	NMIN2	400.000000	NP1PU	0.47078300
NP1PUI	5.3832E-06	NP1RPM	68.1310000	NP1RPMI	7.7905E-04
NP2PU	0.47078300	NP2PUI	5.3832E-06	NP2RMPI	7.7905E-04
NP2RPM	68.1310000	NPRPMB	144.719000	NPRPSB	2.41200000
NPT1B	3600.00000	NPT1ORD	3600.00000	NPT1ORDI	3600.00000
NPT1R	3600.00000	NPT1RI	3600.00000	NPTL1	3599.49000
NPTQ1	158.046000	NPTQ1I	158.068000	NPTR1	3599.47000
NPTR1I	3600.00000	NREF1	3672.00000	NSET2	900.000000
P1	0.16000000	P2	14.6960000	P2T21	5.50753000
P541	34.4802000	P541I	21.3889000	P54L1	34.4802000
P54LL1	34.9975000	P54Q1	2.38143000	P54Q1I	1.47725000
P54R21	34.5283000	P54R21I	21.3889000	PAMB	14.6960000
PCNTRL1	0.26318400	PCNTRL1I	0.	PCTID1	0.01000000
PHIPM1	2.20000000	PHISM1	0.20000000	PNGG1	82.2326000
PNGGR1	82.2326000	PNGGR1I	73.2049000	PS31	138.696000
PS31I	68.0631000	PS3R21	138.696000	PS3R21I	68.0631000
PS3WC1	138.696000	PWRD1	34.7427000	PWRD1I	0.
Q1	0.12000000	Q41	11715.4000	Q4R21	11715.4000
QCAL1	10232.4000	QCAL1I	0.	QGB	36520.0000
QH1	-0.90044000	QLID1	364.623000	QLID1I	364.730000
QMAP1	1857.89000	QMAP1I	0.	QMAPL1	1857.90000
QP1	229329.000	QP1F	6198.26000	QP1FI	92443.6000
QP1I	-0.23332300	QP1PU	0.18508100	QP1PUI	-1.8831E-07
QP2	229329.000	QP2F	6198.26000	QP2FI	92443.6000
QP2I	-0.23332300	QP2PU	0.18508100	QP2PUI	-1.8831E-07
QPBASE	1.2391E+06	QPSBAF	92466.4000	QPT1	13034.7000
QPT1B	36473.0000	QPT1I	364.730000	QPT1PU	0.35692000

QREF1	45000.0000	RDC1	0.02000000	RS1PU0	0.10503100
RS1PU1	-0.00622202	RS1PU2	0.09894770	RS1PU3	0.10351000
RS1PU	0.30126600	RS1PUI0	0.	RS1PUI1	0.
RS1PUI2	0.	RS1PUI3	0.	RS1PUI	0.
SEAFRQ	1.04720000	SEATIME	0.	SNEGVL1	0.
SPDERR1IC	0.	SPDERR2	-9.10852000	SPDREF1	0.50000000
SPEEDERR1	0.04579310	SQRTH2	1.00000000	SWITCHVAR1	0.02905200
T0SEA	0.	T2	518.700000	T41	2219.07000
T4P1	2220.20000	T4PL1	2214.47000	T4R21	2220.20000
T4U1	90.5831000	T511	1593.90000	T51P1	1598.35000
T51PL1	1572.16000	T51Q1	0.99721900	T51R21	1598.35000
T51U1	398.157000	T541	1079.82000	TABTR11	2.04433000
LPHA1(32)	999.900000	Z99976(16)	108.000000	Z99977(16)	999.900000
TAMB	59.0000000	TAUBETAR1	0.01000000	TAUEAFG1	0.10000000
TAUEAFG2	0.10000000	TAUEAFM1	0.05000000	TAUFAST1	0.10000000
TAUGOV2	2.00000000	TAUSLOW1	20.0000000	TAUSPEED1	20.0000000
TC11	3.00000000	TDOPG1	3.19000000	TDOPG2	3.79000000
TDOPM1	2.10000000	TDOPPG1	0.04000000	TDOPPG2	0.38000000
TDOPPM1	0.03900000	TDT541(48)	99999.0000	Z99968(36)	68.3000000
99969(12)	99999.0000	TEG1	-0.34702900	TEG1IC	0.
TEG2	0.	TEM1	0.18514900	TESM1	12673.5000
TESM1I	0.	TGLAG1	7.19854000	THDOT21	0.
THET2N	1.00000000	THETA2	1.00000000	THRESHOLD1	0.10000000
THTA2V	1.00000000	TIC1	69.1485000	TIC1LL	13.0000000
TIC1UL	113.500000	TICMD1	69.1485000	TICMD1I	13.0000000
TICN1	0.19431200	TICN1I	0.	TICRL1LL	-89.0000000
TICRL1UL	22.5000000	TICS1	68.9542000	TICS1I	13.0000000
TMAP(116)	950.000000	Z99997(96)	0.92280000	Z99998(20)	950.000000
TMG2	1.4826E-09	TMM1	-0.18508100	TMM2	-0.18508100
TORQ2	0.	TP1PU	0.16911700	TP1PUI	0.
TP2PU	0.16911700	TP2PUI	0.	TQOPPG1	0.09000000
TQOPPG2	0.19000000	TQOPPM1	0.19300000	TSEA	6.00000000
TSTOP	25.0000000	TURBOLAG2	0.50000000	TUT4H1	0.31613800
TUT51H1	0.13107100	TVSOREF	696.262000	U1	0.30078100
U1D	6.2585E-05	UMAX1	0.99000000	UMIN1	0.
VDBIC	0.	VDBUS	0.35020900	VDCBG2	1.1644E-24
VDERR	0.	VDG1	0.32437900	VDG2	1.1644E-24
VDI1	-0.09046270	VDM1	-0.07600180	VDR1	0.35760000
VERRG1	0.01819210	VERRG2	0.00999999	VI1	-0.45371400
VN1	7.34400000	VNSF1	500.000000	VQ1	9.00000000
VQBIC	1.00000000	VQBUS	0.87214100	VQCBG2	1.00000000
VQERR	0.	VQG1	0.93726200	VQG2	1.00000000
VQI1	0.45726300	VQM1	0.47712900	VQR1	0.84870700
VQSF1	5000.00000	VR1	0.45817000	VRATE1	0.
VRSF1	360.000000	VS1PU0	1.0000E-05	VS1PU10	0.00122748
VS1PU10I	0.	VS1PU2	0.26169900	VS1PU2I	0.
VS1PU3	0.13387600	VS1PU3I	0.	VS1PU4	0.06848660
VS1PU4I	0.	VS1PU5	0.03503540	VS1PU5I	0.
VS1PU6	0.01792290	VS1PU6I	0.	VS1PU7	0.00916874
VS1PU7I	0.	VS1PU8	0.00469042	VS1PU8I	0.
VS1PU9	0.00239946	VS1PU9I	0.	VS1PU	0.51156600
VT12	0.88327600	VTG1	0.99180800	VTG2	1.00000000
VTM1	0.48314500	VTOP1	0.	VTREFG1	1.01000000
VTREFG2	1.01000000	VTRQGS1	0.	W41	80.1019000
W4R21	80.1019000	W541	89.5631000	W54R21	89.5631000

WAVE	4.00000000	WEFSEA	1.04720000	WESEA	0.
WESEAMG	0.	WESMAX	0.10000000	WFAC1	6519.46000
WFSR21	5062.36000	WFUEL1	5067.76000	WFUEL1I	2185.21000
WMG1	376.945000	WMG2D	1.4632E-07	WMM1D	0.00998080
WO	377.000000	WRN1ORD	1.00000000	WRN1ORDIC	1.00000000
WRNG1	0.99985400	WRNG1IC	1.00000000	WRNG2	1.01010000
WRNM1	0.45420700	WRNM2	0.45420700	XDC1	1.68000000
XDG1	1.77000000	XDG2	1.63000000	XDM1	1.76000000
XDMXQM1	0.60300000	XDPG1	0.18000000	XDPG2	0.25000000
XDPM1	0.60800000	XDPPG1	0.15000000	XDPPG2	0.18000000
XDPPM1	0.54200000	XG1	0.10000000	XG2	0.10000000
XK3L1	2.20000000	XL1	0.10000000	XLG1	0.13000000
XLG2	0.07500000	XLM1	0.33700000	XM1	0.10000000
XMV1	0.52776200	XQG1	1.64000000	XQG2	1.01000000
XQM1	1.15700000	XQPPG1	0.15000000	XQPPG2	0.28000000
XQPPM1	0.49400000	XVS0REF	207.220000	Z99885	0.
Z99886	0.	Z99887	0.	Z99888	0.32210600
Z99889	0.	Z99891	1	Z99892	0.
Z99893	0.	Z99894	0.	Z99895	0.19897000
Z99896	0.	Z99898	1	Z99899	0.87135600
Z99900	0.	Z99901	0.87214100	Z99902	0.87205400
Z99903	0.87220100	Z99905	1	Z99906	0.35020900
Z99907	0.	Z99908	0.35020900	Z99909	0.35027900
Z99910	0.35020100	Z99912	1	Z99920	0.02905200
Z99921	0.02905200	Z99945	7.19897000	Z99946	7.19854000
Z99949	2.04649000	Z99950	2.04433000	Z99960	47
Z99961	40	Z99962	54.3832000	Z99970	23
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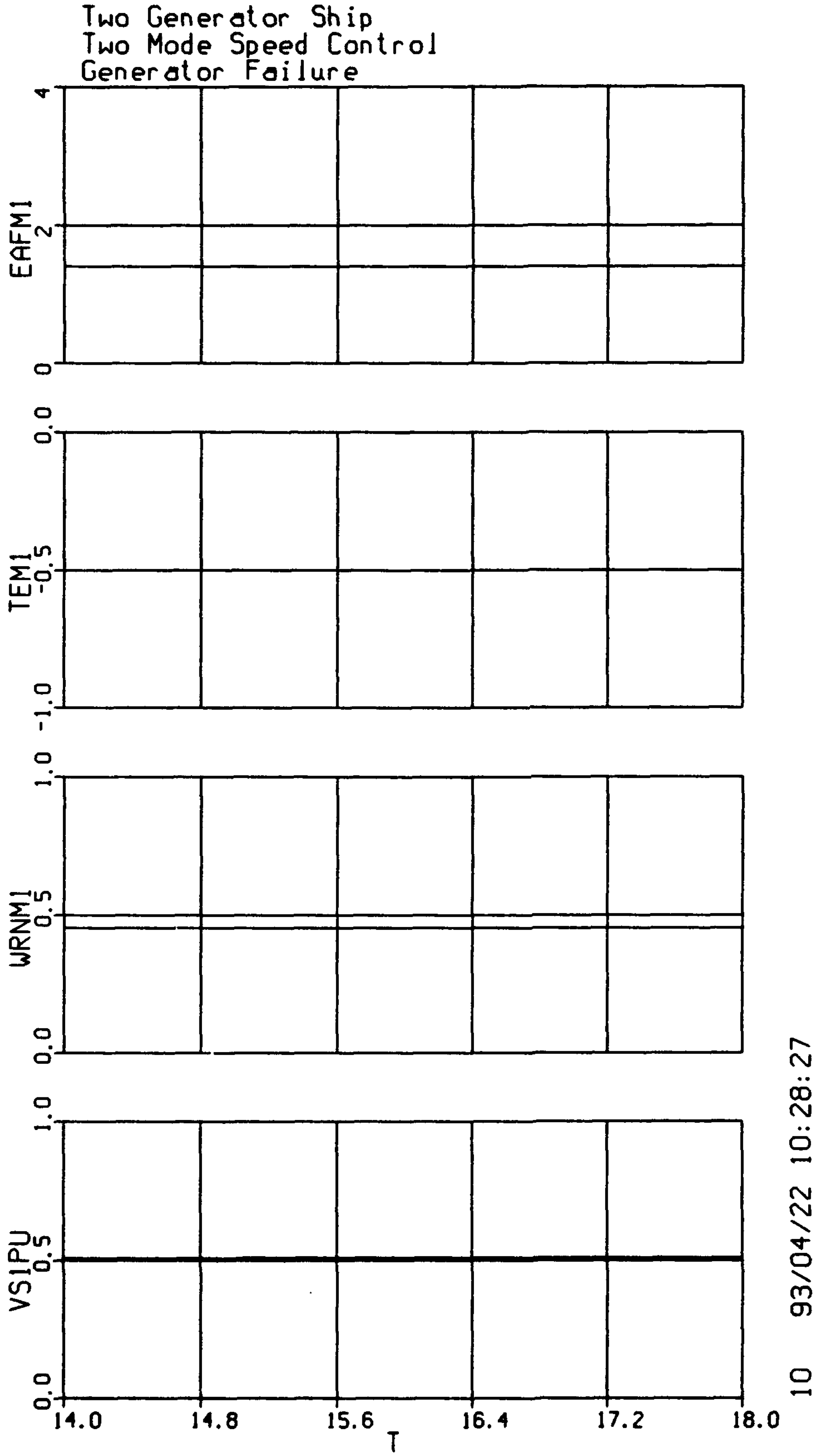
Z99982	116	Z99983	98	Z99984	0.
ZZSEED	55555555				


Two Generator Ship
Two Mode Speed Control
Generator Failure
EAFM1
TEM1
WRNM1
VSIPU
4
2
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0.0
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-1.0
1.0
0.5
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93/04/22 10:28:27
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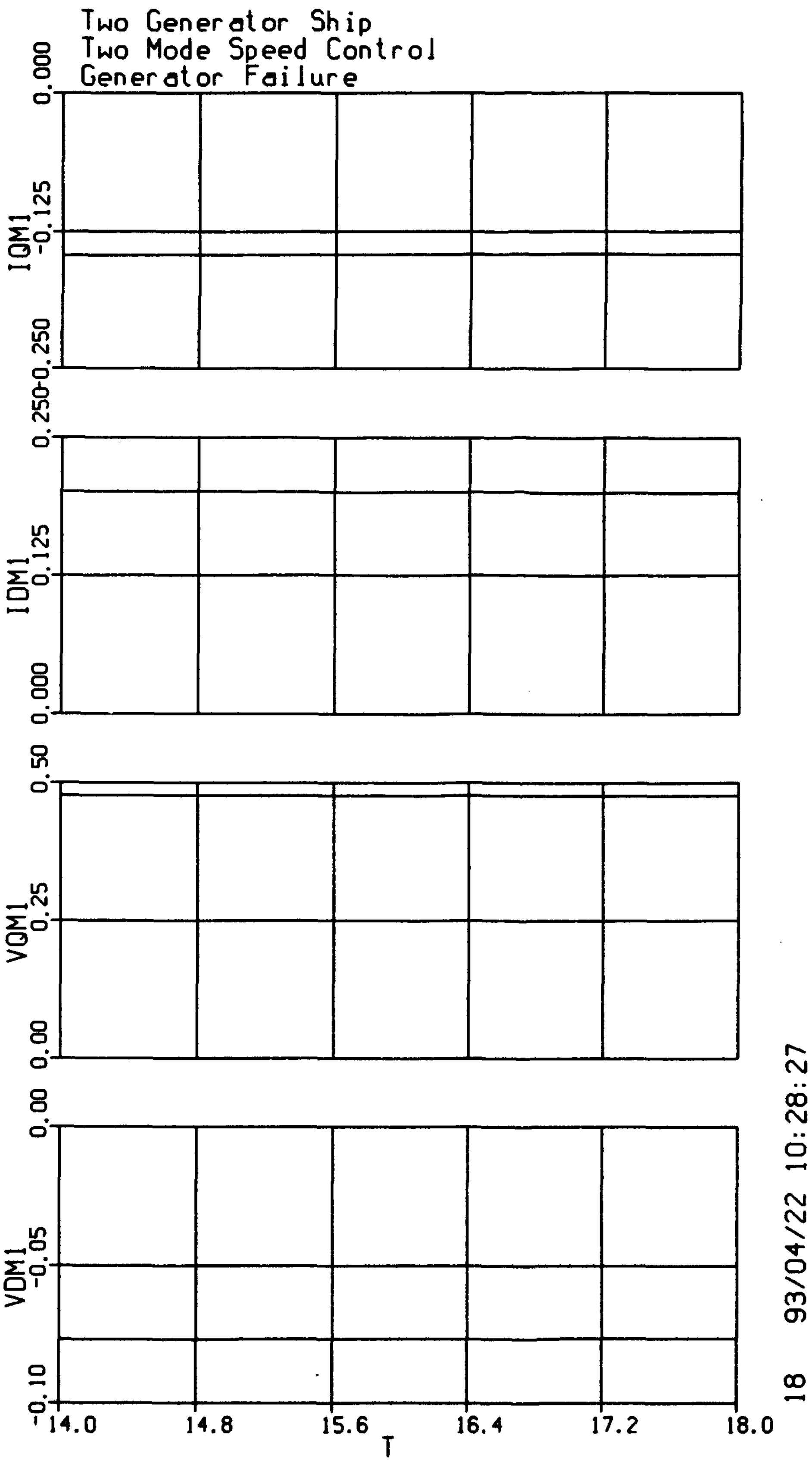

Two Generator Ship
Two Mode Speed Control
Generator Failure
IQM1
0.000
-0.125
-0.250
IDM1
0.250
0.125
0.000
VQM1
0.50
0.25
0.00
VDM1
0.00
-0.05
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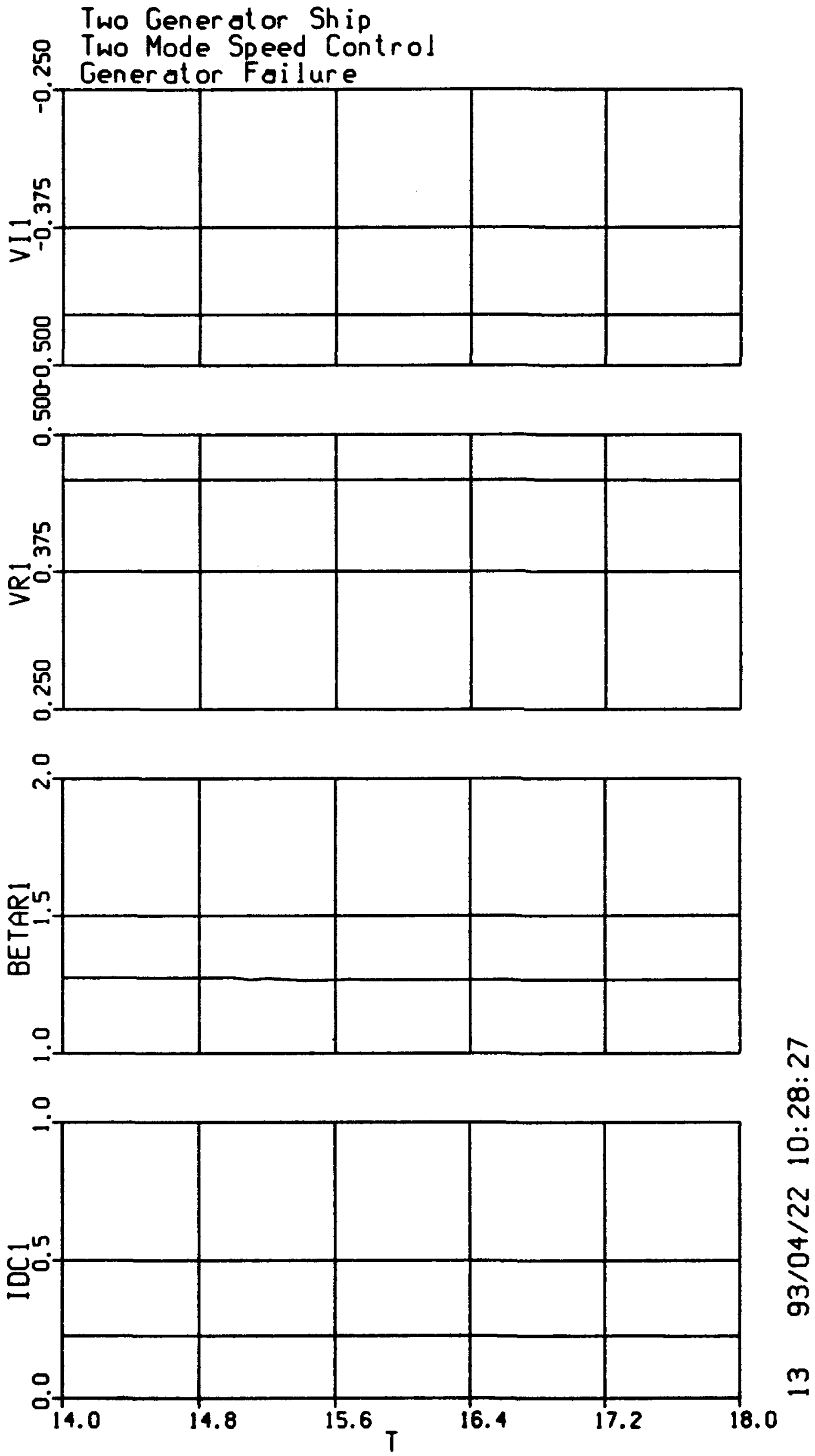
14.0
14.8
15.6
16.4
17.2
18.0
T
93/04/22 10:28:27
18


Two Generator Ship
Two Mode Speed Control
Generator Failure
VI1
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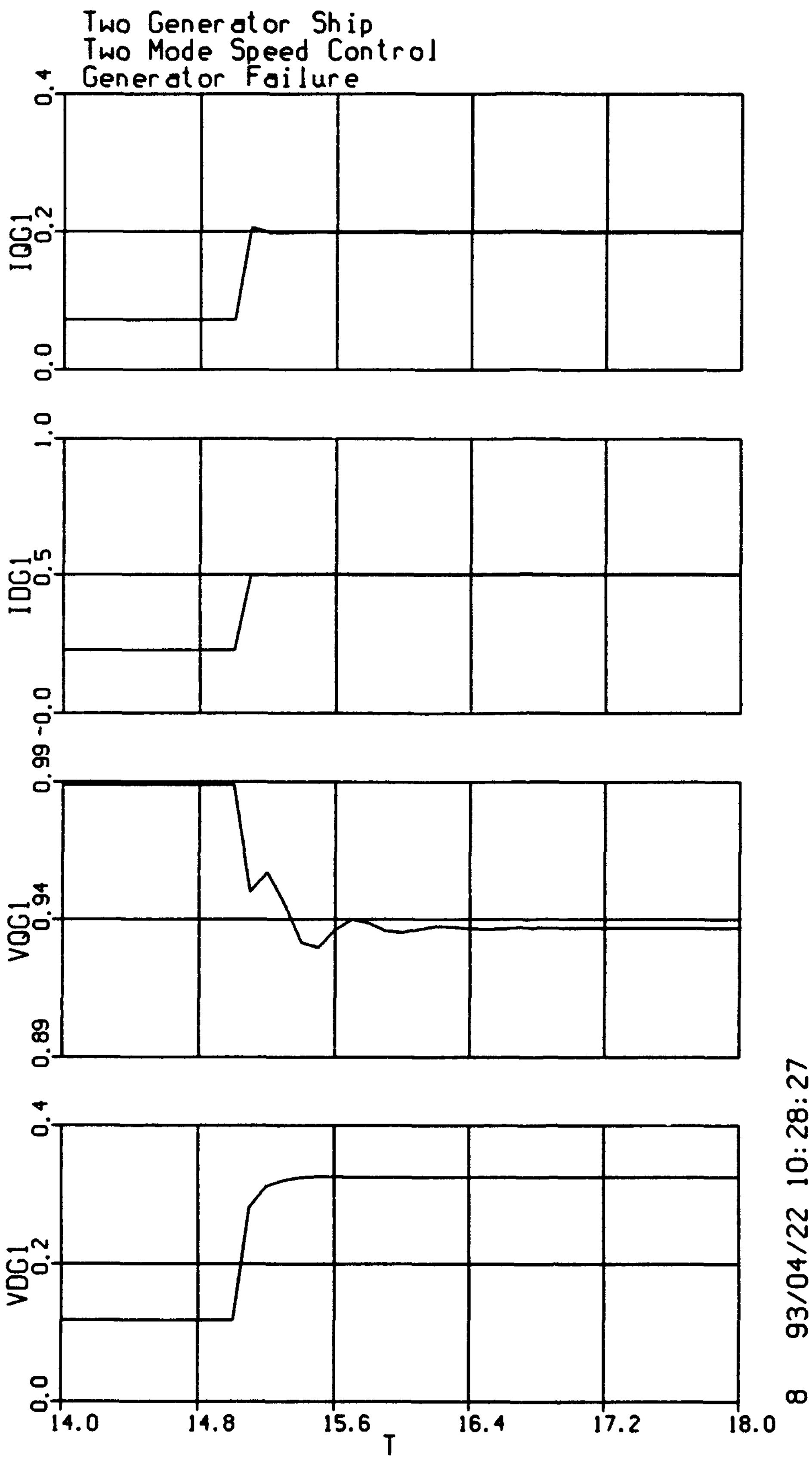
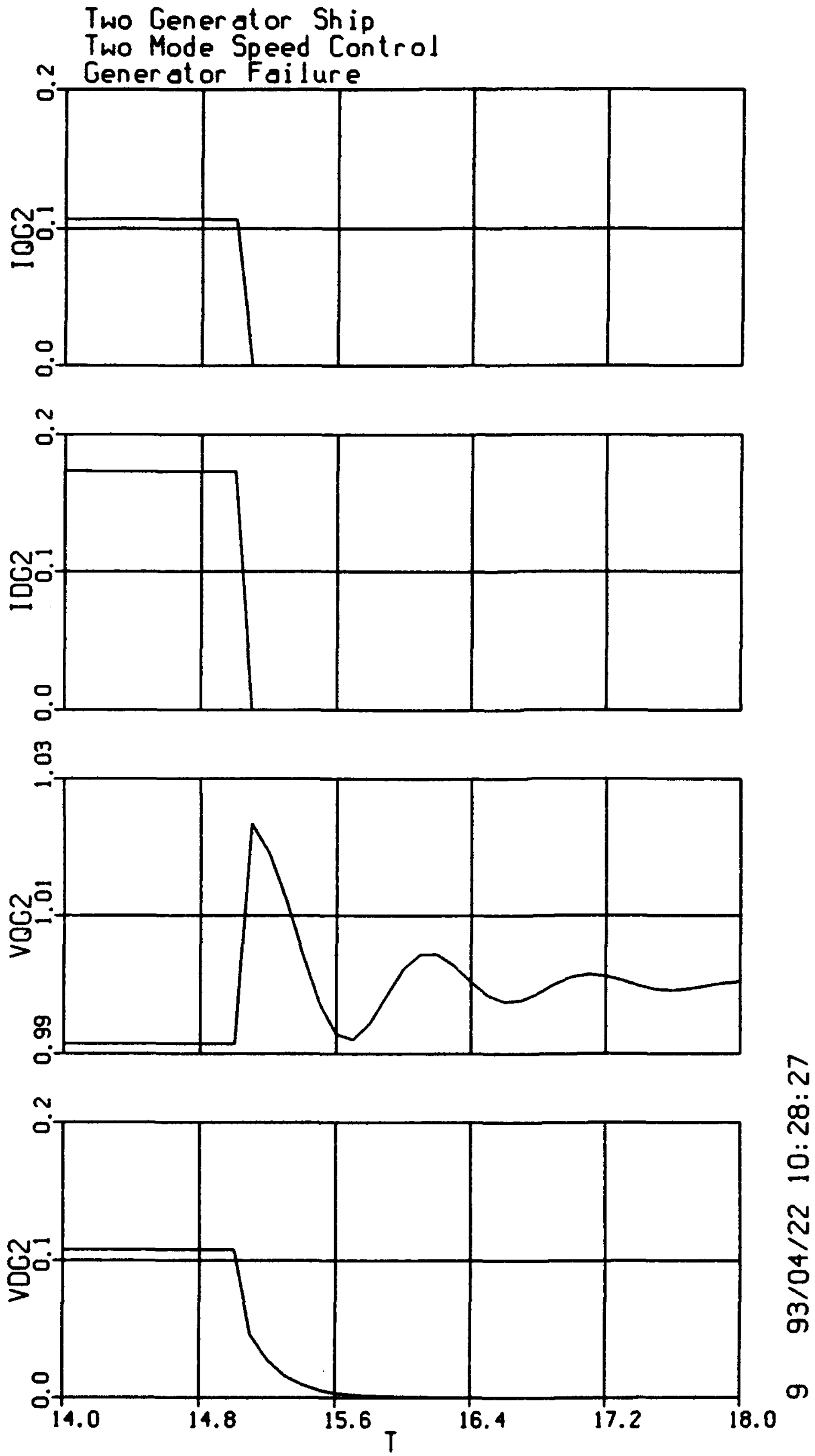
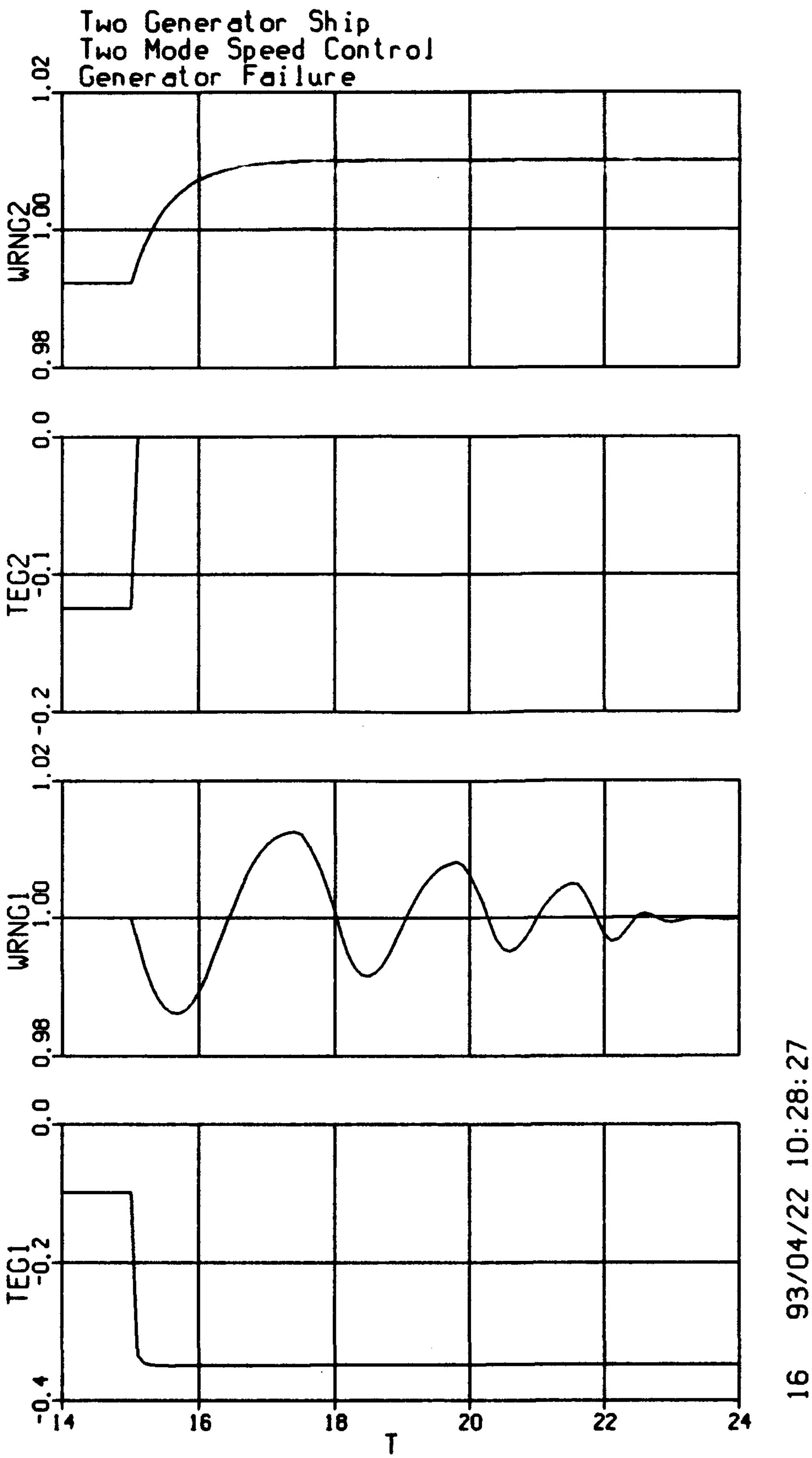
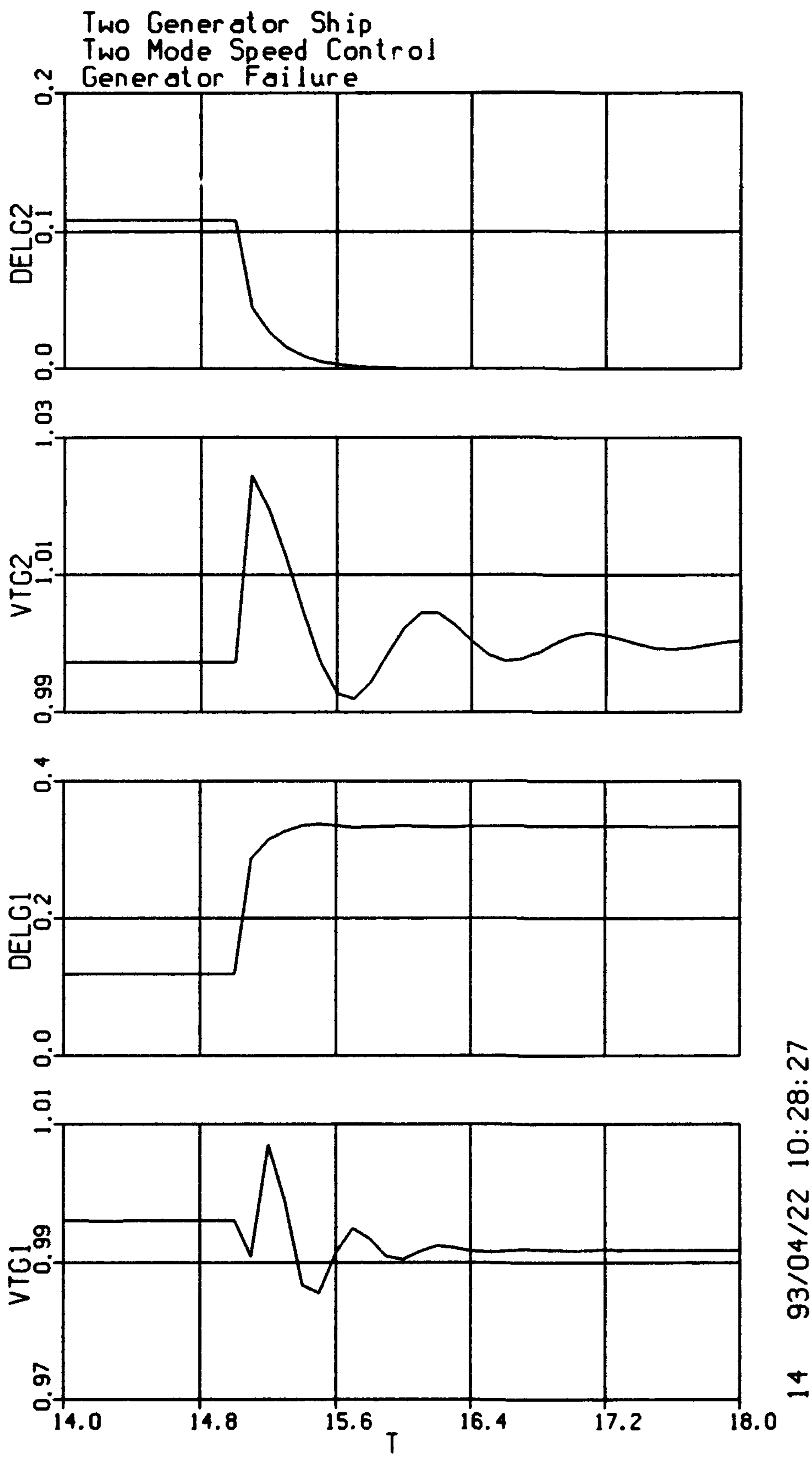
-0.375
-0.500
VR1
0.500
0.375
0.250
BETAR1
2.0
1.5
1.0
IDC1
1.0
0.5
0.0
14.0
14.8
15.6
16.4
17.2
18.0
T
93/04/22 10:28:27
13


Two Generator Ship
Two Mode Speed Control
Generator Failure
IQG1
0.4
0.2
0.0
IDG1
1.0
0.5
-0.0
VQG1
0.99
0.94
0.89
VDG1
0.4
0.2
0.0
14.0
14.8
15.6
16.4
17.2
18.0
T
93/04/22 10:28:27
8


Two Generator Ship
Two Mode Speed Control
Generator Failure
IQG2
IDG2
VQG2
VDG2
0.0
0.1
0.2
0.99
1.01
1.03
14.0
14.8
15.6
16.4
17.2
18.0
T
93/04/22 10:28:27
9



Two Generator Ship
Two Mode Speed Control
Generator Failure
WRNG2
1.02
1.00
0.98
TEG2
0.0
-0.1
-0.2
WRNG1
1.02
1.00
0.98
TEG1
0.0
-0.2
-0.4
14
16
18
20
22
24
T
16 93/04/22 10:28:27


Two Generator Ship
Two Mode Speed Control
Generator Failure
DELG2
0.0
0.1
0.2
VTG2
0.99
1.01
1.03
DELG1
0.0
0.2
0.4
VTG1
0.97
0.99
1.01
14.0
14.8
15.6
16.4
17.2
18.0
T
93/04/22 10:28:27
14

D.7 Generator Failure at 90% Motor Speed

System 2a: Generator #2 tripped off line @ T=15 sec

T	18.1803000	ZZTICG	0.	CINT	0.10000000
ZZIERR	F	ZZNBLK	1	ZZICON	0
ZZSTFL	T	ZZFRFL	F	ZZICFL	F
ZZRNFL	F	ZZJEFL	F	ZZNIST	40
ZZNAST	0	IALG	1	NSTP	10
MAXT	0.10000000	MINT	1.0000E-08		

tate Variables		Derivatives		Initial Conditions	
EDPPG1	0.72011600	Z99995	-1.2195E-04	EDPPG1IC	0.
EDPPG2	1.1850E-08	Z99992	-6.2367E-08	EDPPG2IC	0.
EDPPM1	-0.23329600	Z99930	4.8301E-05	EDPPM1IC	0.
ENPTL1	6.70086000	Z99942	0.20103500	ENPTL1I	7.20000000
EQPG1	0.75499600	Z99994	1.8228E-04	EQPG1IC	1.00000000
EQPG2	0.99920600	Z99991	-0.00232718	EQPG2IC	1.00000000
EQPM1	1.41814000	Z99929	-3.8589E-06	EQPM1IC	1.00000000
EQPPG1	0.72741600	Z99996	1.0163E-04	EQPPG1IC	1.00000000
EQPPG2	1.00012000	Z99993	-0.00241289	EQPPG2IC	1.00000000
EQPPM1	1.38623000	Z99931	3.5195E-05	EQPPM1IC	1.00000000
IDC1	0.54223500	Z99922	-2.6964E-05	IDC1IC	0.
NGG1	9222.09000	Z99965	213.686000	NGG1I	7193.84000
NPT1	3369.03000	Z99978	103.740000	NPT1I	3600.00000
THMM1	43180.3000	Z99927	297.195000	THMM1IC	0.
TICRL1	113.500000	Z99959	7.6294E-05	TICRL1I	13.0000000
WMG2	391.600000	Z99979	0.08838670	WMG2IC	377.000000
WMM1	297.195000	Z99928	-0.00646367	WMM1IC	0.
Z99915	0.	Z99914	0.	Z99913	0.
Z99917	0.86895800	Z99916	3.1753E-05	VS1PUI	0.
Z99919	0.56063000	Z99918	-1.1024E-04	IDCR1IC	0.
Z99924	0.55184400	Z99923	-5.8413E-04	U1IC	0.99000000
Z99926	1.97503000	Z99925	0.12087800	EAFM1IC	1.00000000
Z99933	0.85020400	Z99932	0.04110780	XMV1I	0.31609000
Z99935	9213.43000	Z99934	216.650000	NGGL1I	7193.84000
Z99937	252.498000	Z99936	13.6253000	PS3WC1I	68.0631000
Z99939	0.02055390	Z99938	-0.01249520	EMFFB1I	0.
Z99941	113.455000	Z99940	3.6030E-04	ALPHA1I	40.9791000
Z99944	-321.147000	Z99943	-9.62277000	TGLAG1I	-345.140000
Z99948	-9.63467000	Z99947	-0.70087400	TABTR1I	0.
Z99952	7448.08000	Z99951	299.854000	QMAPL1I	0.
Z99954	3354.45000	Z99953	101.262000	NPTL1I	3600.00000
Z99956	57.2223000	Z99955	2.20612000	P54LL1I	21.7097000
Z99958	56.4636000	Z99957	2.14359000	P54L1I	21.3889000
Z99964	1739.47000	Z99963	61.4375000	T51PL1I	1416.04000
Z99967	2615.63000	Z99966	128.343000	T4PL1I	1875.14000
Z99973	0.13876700	Z99972	0.	NERR1I	0.
Z99981	8.9559E-04	Z99980	-0.00163522	TMECH2IC	0.
Z99986	1.00001000	Z99985	0.	FUEL2IC	0.
Z99988	0.97231000	Z99987	0.15422600	EAFG2IC	1.00000000
Z99990	2.21734000	Z99989	0.01030920	EAFG1IC	1.00000000

Algebraic Variables

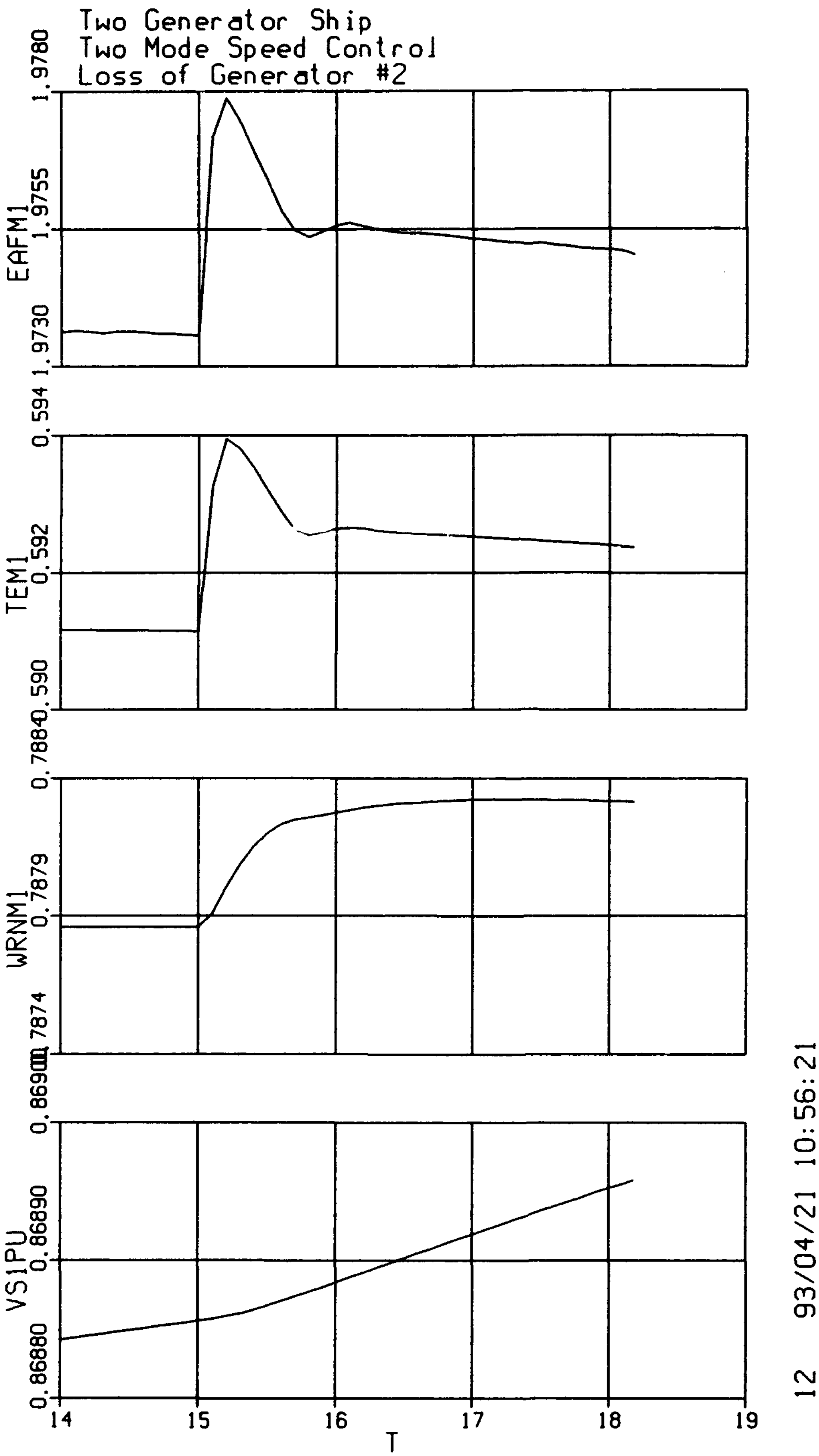
mon Block /ZZCOMU/

AFL1	0.00124403	AFRL1	0.13148200	ALPHA1	113.455000
ALPHA1LL	13.0000000	ALPHA1UL	120.000000	ALPHAG1	54.0000000
ALPHAG2	20.7143000	ALPHAM1	18.4545000	ARLLG1I	0.31609000
BASEKWG1	16200.0000	BASEKWG2	2500.00000	BASEKWM1	14914.0000
BASENG1	3600.00000	BASENG2	900.000000	BASENM1	150.000000
BASEQM1	949455.000	BASEVG1	4160.00000	BASEVG2	450.000000
BASEVM1	5000.00000	BETAI1	2.20000000	BETAM1	2.20000000
BETAMINM1	1.57080000	BETAR1	0.98622300	CQLID1	2.8143E-05
CYL2	8.00000000	DELAY2	0.54768700	DELG1	0.93128300
DELG2	1.1848E-08	DELI1	-0.40188400	DELM1	-0.34744000
DELR1	1.12960000	DELTA2	1.00000000	DELV	1.0000E-04
DELVTQ1	0.	DELWF1	1062.24000	DELWF1I	0.
DFL1	-0.93544600	DFRL1	-0.21369800	DN1	103.740000
DNGG1	9478.28000	DNPT1	103.740000	DNREF1	180.000000
DQ4S1	-396.767000	DQHR21	790.963000	DQPTR1	44713.1000
DRLLG1I	0.31609000	DRPMDT1	0.15117800	DT4HS1	-50.3455000
DT51HS1	-50.5555000	DZ1	0.05000000	E01I	0.
E211	0.00422347	E221	0.25340800	E231	0.08446940
E51	0.58562600	E61	0.	E71	0.18283100
E81	0.	E91	0.74586900	EAFERRM1	6.0439E-05
EAFG1	2.21734000	EAFG1D	0.01030920	EAFG2	0.97231000
EAFG2D	0.15422600	EAFM1	1.97503000	EAFM1D	0.12087800
EAFM1MAX	3.00000000	EAFM1MIN	0.	EAFMAXG1	3.00000000
EAFMAXG2	3.00000000	EAFMING1	0.	EAFMING2	0.
EAFSM1	1.97509000	EDPPG1D	-1.2195E-04	EDPPG2D	-6.2367E-08
EDPPM1D	4.8301E-05	EI1	0.91044500	EISM1	1.00000000
EMFFB1	0.02055390	EMFSAT1	0.00124403	ENGG1	0.20020900
ENPT1	6.70890000	ENPT1I	7.20000000	EPM1	1.68360000
EQPG1D	1.8228E-04	EQPG2D	-0.00232718	EQPM1D	-3.8589E-06
EQPPG1D	1.0163E-04	EQPPG2D	-0.00241289	EQPPM1D	3.5195E-05
ER1	0.98280500	ERRBOUND	1.0000E-04	ERX1	0.00124403
FARG0	0	FARG1	1	FARG2	2
FARG3	3	FARGS0	0	FARGS1	1
FARGS2	2	FARGS3	3	FUEL2	0.
FUEL2MAX	1.00000000	FUEL2MIN	0.	FUELAG2	0.04813480
G11	0.22000000	G31	0.50000000	G51	0.50000000
GBETAR1	30.0000000	GEAFG1	100.000000	GEAFG2	100.000000
GEAFM1	100.000000	GLARGE1	50.0000000	GM1	1.50000000
GSMALL1	5.00000000	GSPEED1	5.00000000	HG1	0.92400000
HG2	1.91000000	HHPS	0.51678100	HM1	1.28978000
HP1	23742.4000	HP1B	25000.0000	HP1D	23742.4000
HP1I	0.	HP1ORD	0.	HP1ORDI	0.
HPT1ORD	23742.4000	IAJXQM1	0.69177000	IAM1	0.59790000
ICLIM1	70.0000000	ICNTRL1	0.13876700	ICNTRL1I	0.
ID1GR	1.00000000	IDBM1	0.	IDC1D	-2.6964E-05
IDCBG2	0.	IDCOM1	0.56063000	IDCR1	0.56063000
IDCR1D	-1.1024E-04	IDCR1DMAX	5.00000000	IDCR1DMIN	-5.00000000
IDCR1MAX	0.80000000	IDCR1MIN	0.	IDG1	0.91921200
IDG1IC	0.	IDG1M1	1.20009000	IDG2	0.
IDG2ERR	0.	IDG2IC	0.	IDG2M1	0.
IDI1	0.48340000	IDL2	0.20285400	IDM1	0.48340000
IDM1IC	0.	IDR1	0.49861700	IDXM1	0.29149000

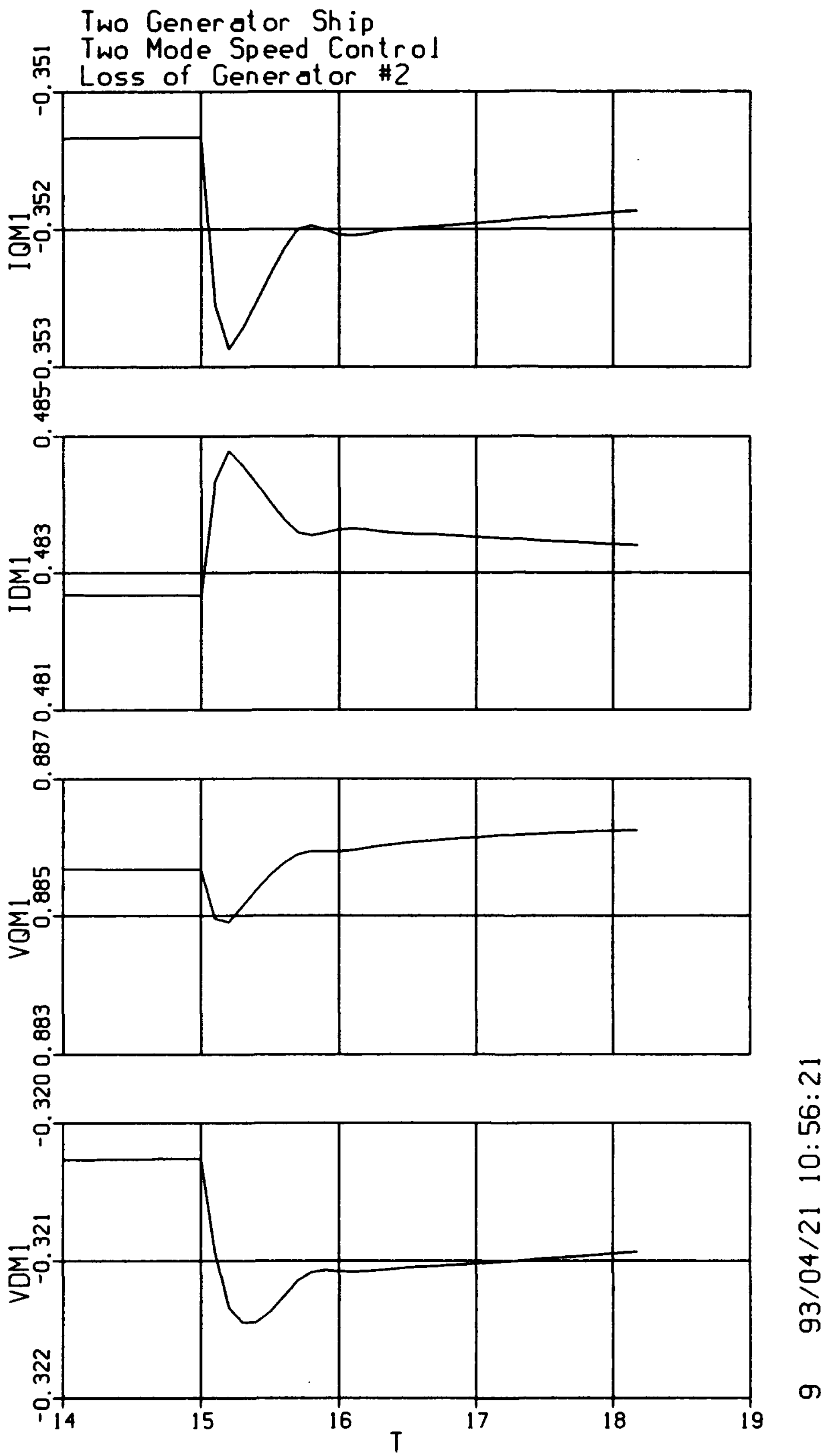
IERR1	0.01839460	IERR1IC	0.	IGG1	566.778000
IITID1	580.484000	IQBM1	0.	IQCBG2	0.
IQG1	0.48329200	IQG1IC	0.	IQG1M1	0.63096800
IQG2	0.	IQG2ERR	0.	IQG2IC	0.
IQG2M1	0.	IQI1	-0.35186500	IQL2	-0.02892660
IQM1	-0.35186500	IQM1IC	0.	IQR1	0.32994700
JJG	16505.0000	JJPROP	1.3130E+06	JJPS	1.4790E+06
JJPT1	2171.50000	JJSHFT	166000.000	K00RES	0.
K01RES	0.20233900	K02RES	-0.05737380	K03RES	0.96980600
K04RES	-0.23175100	K05RES	8.65721000	K06RES	-5.19908000
K07RES	-23.5963000	K08RES	15.9458000	K09RES	20.3595000
K10RES	-15.1637000	KALARM1	1	KBRAKE	1.00000000
KC11	0.50000000	KDFRQ	1.57080000	KGC	32.1740000
KGOV2	0.20000000	KHOLDPI1	0.	KI	307.240000
KIG1M1	1.30556000	KIG2M1	1.86253000	KIR	2.00000000
KKWG1M1	1.08623000	KKWG2M1	0.16762800	KPNGG1	0.01017600
KQHP	5252.10000	KRAT1	0.16000000	KRATE1	10.0000000
KSHTDN1	1	KTBL1	0	KTURBO2	0.50000000
KVG1M1	0.83200000	KVG2M1	0.09000000	KVSHIP	0.00754970
KZG1M1	0.63727300	KZG2M1	0.04832140	LBRAKE	F
LCBG2	F	LDOPLR	F	LFWD1	T
LHEADR	F	LHOLD1PI	T	LNGG1A	F
LPWRD1	F	LSEA	F	LT541A	T
MAXIT	10.0000000	MFKAC1	0.58200000	MFKFR1	0.17259000
MFKMV1	23.0000000	MFKN1	4.6080E-08	MFW1	159.400000
	2091.30000		13659.6000	N1	3369.03000
N1I	3600.00000	N2	934.875000	NERR1	230.969000
NGB	3600.00000	NGG1B	9827.00000	NGGL1	9213.43000
NMAX2	950.000000	NMIN2	400.000000	NP1PU	0.81708400
NP1PUI	5.3832E-06	NP1RPM	118.247000	NP1RPMI	7.7905E-04
NP2PU	0.81708400	NP2PUI	5.3832E-06	NP2RMPI	7.7905E-04
NP2RPM	118.247000	NPRPMB	144.719000	NPRPSB	2.41200000
NPT1B	3600.00000	NPT1ORD	3600.00000	NPT1ORDI	3600.00000
NPT1R	3600.00000	NPT1RI	3600.00000	NPTL1	3354.45000
NPTQ1	147.287000	NPTQ1I	158.068000	NPTR1	3369.03000
NPTR1I	3600.00000	NREF1	3672.00000	NSET2	900.000000
P1	0.16000000	P2	14.6960000	P2T21	5.50753000
P541	56.4936000	P541I	21.3889000	P54L1	56.4636000
P54LL1	57.2223000	P54Q1	3.89374000	P54Q1I	1.47725000
P54R21	57.1851000	P54R21I	21.3889000	PAMB	14.6960000
PCNTRL1	115.485000	PCNTRL1I	0.	PCTID1	0.01000000
PHIPM1	2.20000000	PHISM1	0.20000000	PNGG1	93.8444000
PNGGR1	93.8444000	PNGGR1I	73.2049000	PS31	253.043000
PS31I	68.0631000	PS3R21	253.043000	PS3R21I	68.0631000
PS3WC1	252.498000	PWRD1	94.9695000	PWRD1I	0.
Q1	0.12000000	Q41	23079.1000	Q4R21	23079.1000
QCAL1	41020.6000	QCAL1I	0.	QGB	36520.0000
QH1	394.196000	QLID1	319.431000	QLID1I	364.730000
QMAP1	7457.08000	QMAP1I	0.	QMAPL1	7448.08000
QP1	734052.000	QP1F	10721.0000	QP1FI	92443.6000
QP1I	-0.23332300	QP1PU	0.59242100	QP1PUI	-1.8831E-07
QP2	734052.000	QP2F	10721.0000	QP2FI	92443.6000
QP2I	-0.23332300	QP2PU	0.59242100	QP2PUI	-1.8831E-07
QPBASE	1.2391E+06	QPSBAF	92466.4000	QPT1	43638.4000
QPT1B	36473.0000	QPT1I	364.730000	QPT1PU	1.19492000

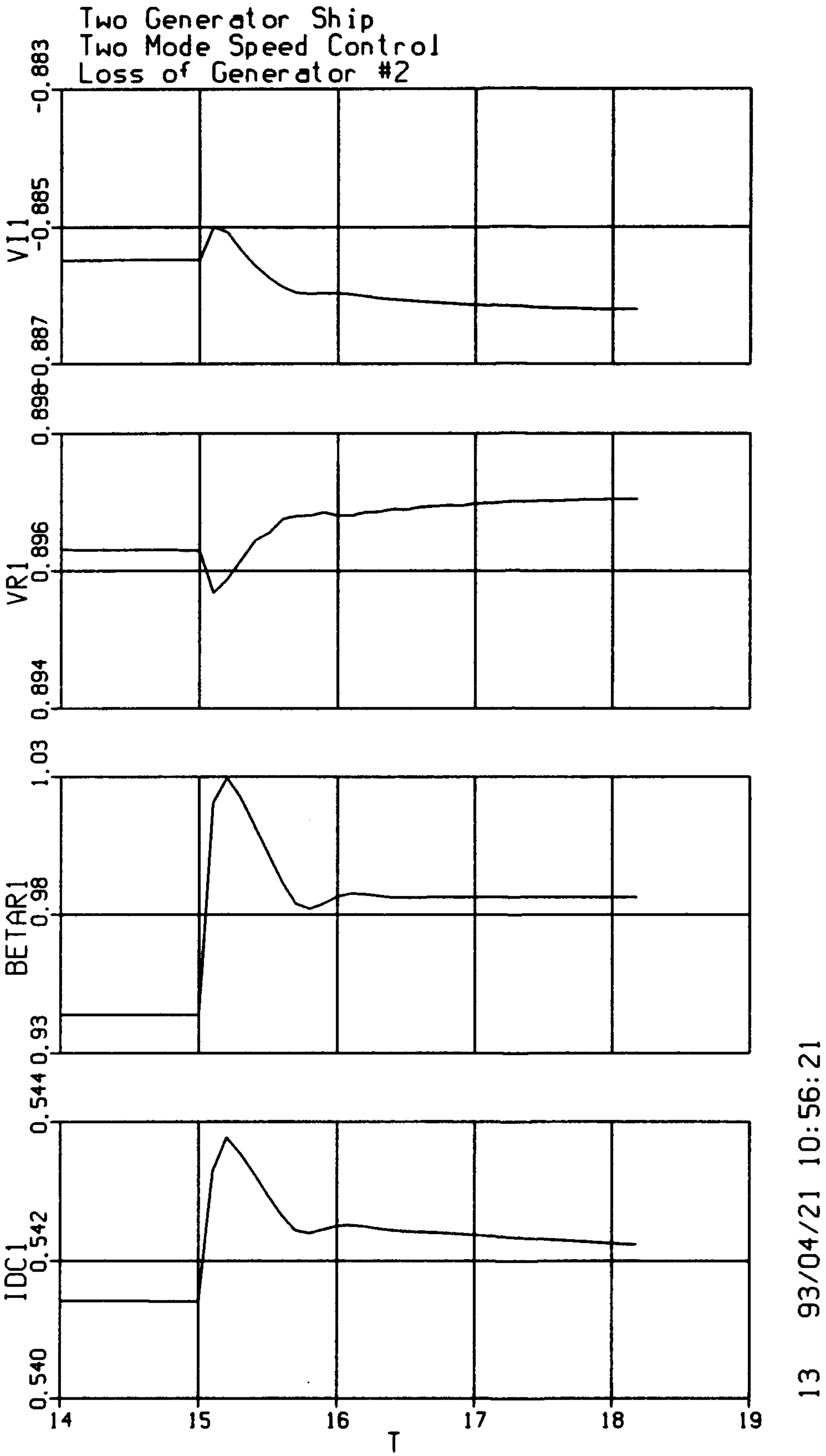
QREF1	45000.0000	RDC1	0.02000000	RS1PU0	7.21271000
RS1PU1	-6.77660000	RS1PU2	0.46087200	RS1PU3	0.17582400
RS1PU	1.07280000	RS1PUI0	0.	RS1PUI1	0.
RS1PUI2	0.	RS1PUI3	0.	RS1PUI	0.
SEAFRQ	1.04720000	SEATIME	0.	SNEGVL1	0.
SPDERR1IC	0.	SPDERR2	-34.8749000	SPDREF1	0.90000000
SPEEDERR1	0.11168500	SQRTH2	1.00000000	SWITCHVAR1	0.09909070
T0SEA	0.	T2	518.700000	T41	2878.14000
T4P1	2928.49000	T4PL1	2615.63000	T4R21	2928.49000
T4U1	6414.56000	T511	2052.84000	T51P1	2103.39000
T51PL1	1739.47000	T51Q1	0.97596500	T51R21	2103.39000
T51U1	7127.20000	T541	1530.03000	TABTR11	8.41437000
LPHA1(32)	*999.900000*	Z99976(16)	*108.000000*	Z99977(16)	*999.900000*
TAMB	59.0000000	TAUBETAR1	0.01000000	TAUEAFG1	0.10000000
TAUEAFG2	0.10000000	TAUEAFM1	0.05000000	TAUFAST1	0.10000000
TAUGOV2	2.00000000	TAUSLOW1	20.0000000	TAUSPEED1	20.0000000
TC11	3.00000000	TDOPG1	3.19000000	TDOPG2	3.79000000
TDOPM1	2.10000000	TDOPPG1	0.04000000	TDOPPG2	0.38000000
TDOPPM1	0.03900000	TDT541(48)	99999.0000	Z99968(36)	68.3000000
99969(12)	99999.0000	TEG1	-1.01349000	TEG1IC	0.
TEG2	0.	TEM1	0.59237700	TESM1	37012.8000
TESM1I	0.	TGLAG1	7.16117000	THDOT21	3.4987E-04
THET2N	1.00000000	THETA2	1.00000000	THRESHOLD1	0.10000000
THTA2V	1.00000000	TIC1	113.500000	TIC1LL	13.0000000
TIC1UL	113.500000	TICMD1	212.142000	TICMD1I	13.0000000
TICN1	115.623000	TICN1I	0.	TICRL1LL	-89.0000000
TICRL1UL	22.5000000	TICS1	96.4793000	TICS1I	13.0000000
TMAP(116)	950.000000	Z99997(96)	0.92280000	Z99998(20)	950.000000
TMG2	8.9559E-04	TMM1	-0.59242100	TMM2	-0.59242100
TORQ2	0.	TP1PU	0.53850400	TP1PUI	0.
TP2PU	0.53850400	TP2PUI	0.	TQOPPG1	0.09000000
TQOPPG2	0.19000000	TQOPPM1	0.19300000	TSEA	6.00000000
TSTOP	20.0000000	TURBOLAG2	0.49955300	TUT4H1	0.41022900
TUT51H1	0.16882000	TVSOREF	696.262000	U1	0.55184400
U1D	-5.8413E-04	UMAX1	0.99000000	UMIN1	0.
VDBIC	0.	VDBUS	0.85570000	VDCBG2	1.1850E-08
VDERR	0.	VDG1	0.79261000	VDG2	1.1850E-08
VDI1	-0.35612300	VDM1	-0.32093600	VDR1	0.88869400
VERRG1	0.02218370	VERRG2	0.00987732	VI1	-0.88620300
VN1	7.34400000	VNSF1	500.000000	VQ1	9.00000000
VQBIC	1.00000000	VQBUS	0.46953700	VQCBG2	1.00012000
VQERR	0.	VQG1	0.58953400	VQG2	1.00012000
VQI1	0.83790600	VQM1	0.88624600	VQR1	0.41967500
VQSF1	5000.00000	VR1	0.89704700	VRATE1	0.
VRSF1	360.000000	VS1PU0	1.0000E-05	VS1PU10	0.24546500
VS1PU10I	0.	VS1PU2	0.75508800	VS1PU2I	0.
VS1PU3	0.65614000	VS1PU3I	0.	VS1PU4	0.57015800
VS1PU4I	0.	VS1PU5	0.49544400	VS1PU5I	0.
VS1PU6	0.43052000	VS1PU6I	0.	VS1PU7	0.37410400
VS1PU7I	0.	VS1PU8	0.32508100	VS1PU8I	0.
VS1PU9	0.28248200	VS1PU9I	0.	VS1PU	0.86895800
VT12	0.95268700	VTG1	0.98781600	VTG2	1.00012000
VTM1	0.94256700	VTOP1	0.	VTREFG1	1.01000000
VTREFG2	1.01000000	VTRQGS1	0.	W41	127.411000
W4R21	127.411000	W541	140.978000	W54R21	140.978000

WAVE	4.00000000	WEFSEA	1.04720000	WESEA	0.
WESEAMG	0.	WESMAX	0.10000000	WFAC1	12363.8000
WFSR21	11275.1000	WFUEL1	12337.4000	WFUEL1I	2185.21000
WMG1	352.812000	WMG2D	0.08838670	WMM1D	-0.00646367
WO	377.000000	WRN1ORD	1.00000000	WRN1ORDIC	1.00000000
WRNG1	0.93584200	WRNG1IC	1.00000000	WRNG2	1.03873000
WRNM1	0.78831500	WRNM2	0.78831500	XDC1	1.68000000
XDG1	1.77000000	XDG2	1.63000000	XDM1	1.76000000
XDMXQM1	0.60300000	XDPG1	0.18000000	XDPG2	0.25000000
XDPM1	0.60800000	XDPPG1	0.15000000	XDPPG2	0.18000000
XDPPM1	0.54200000	XG1	0.10000000	XG2	0.10000000
XK3L1	2.20000000	XL1	0.10000000	XLG1	0.13000000
XLG2	0.07500000	XLM1	0.33700000	XM1	0.10000000
XMV1	0.87075800	XQG1	1.64000000	XQG2	1.01000000
XQM1	1.15700000	XQPPG1	0.15000000	XQPPG2	0.28000000
XQPPM1	0.49400000	XVSOREF	207.220000	Z99885	0.
Z99886	0.	Z99887	0.	Z99888	0.62855300
Z99889	0.	Z99891	1	Z99892	0.
Z99893	0.	Z99894	0.	Z99895	0.54962200
Z99896	0.	Z99898	1	Z99899	0.46934900
Z99900	0.	Z99901	0.46953800	Z99902	0.46949000
Z99903	0.46952500	Z99905	1	Z99906	0.85570000
Z99907	0.	Z99908	0.85570000	Z99909	0.85587100
Z99910	0.85570700	Z99912	1	Z99920	0.09909070
Z99921	0.09909070	Z99945	6.70890000	Z99946	7.16117000
Z99949	8.20411000	Z99950	8.41437000	Z99960	47
Z99961	41	Z99962	63.1062000	Z99970	29
Z99971	96.4793000	Z99974	18	Z99975	13.0000000
Z99982	116	Z99983	98	Z99984	0.
ZZSEED	55555555				

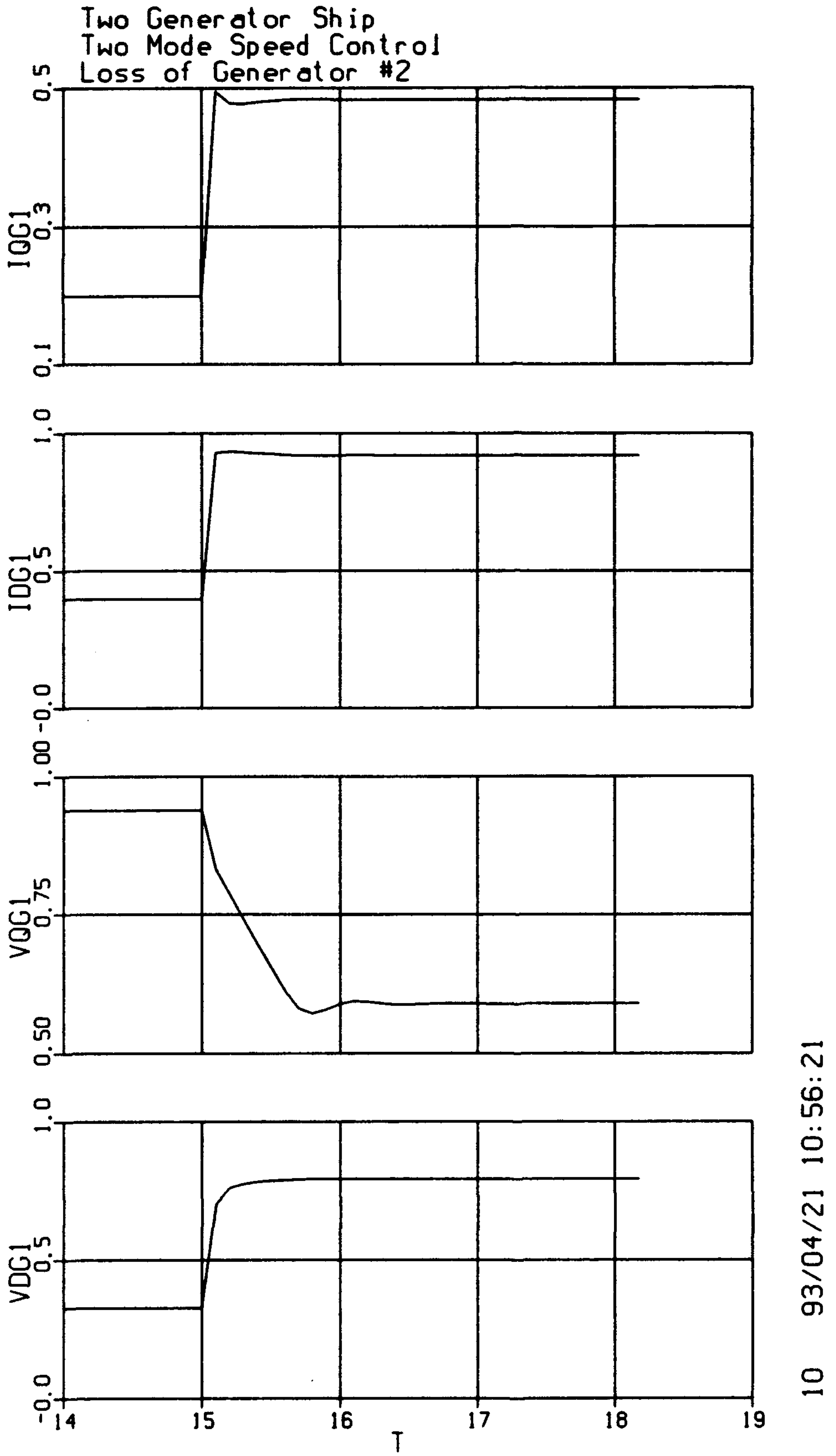


Two Generator Ship
Two Mode Speed Control
Loss of Generator #2
EAFM1
1.9780
1.9755
1.9730
TEM1
0.594
0.592
0.590
WRNM1
0.7884
0.7879
0.7874
VS1PU
0.86900
0.86890
0.86880
14
15
16
17
18
19
T
93/04/21 10:56:21
12

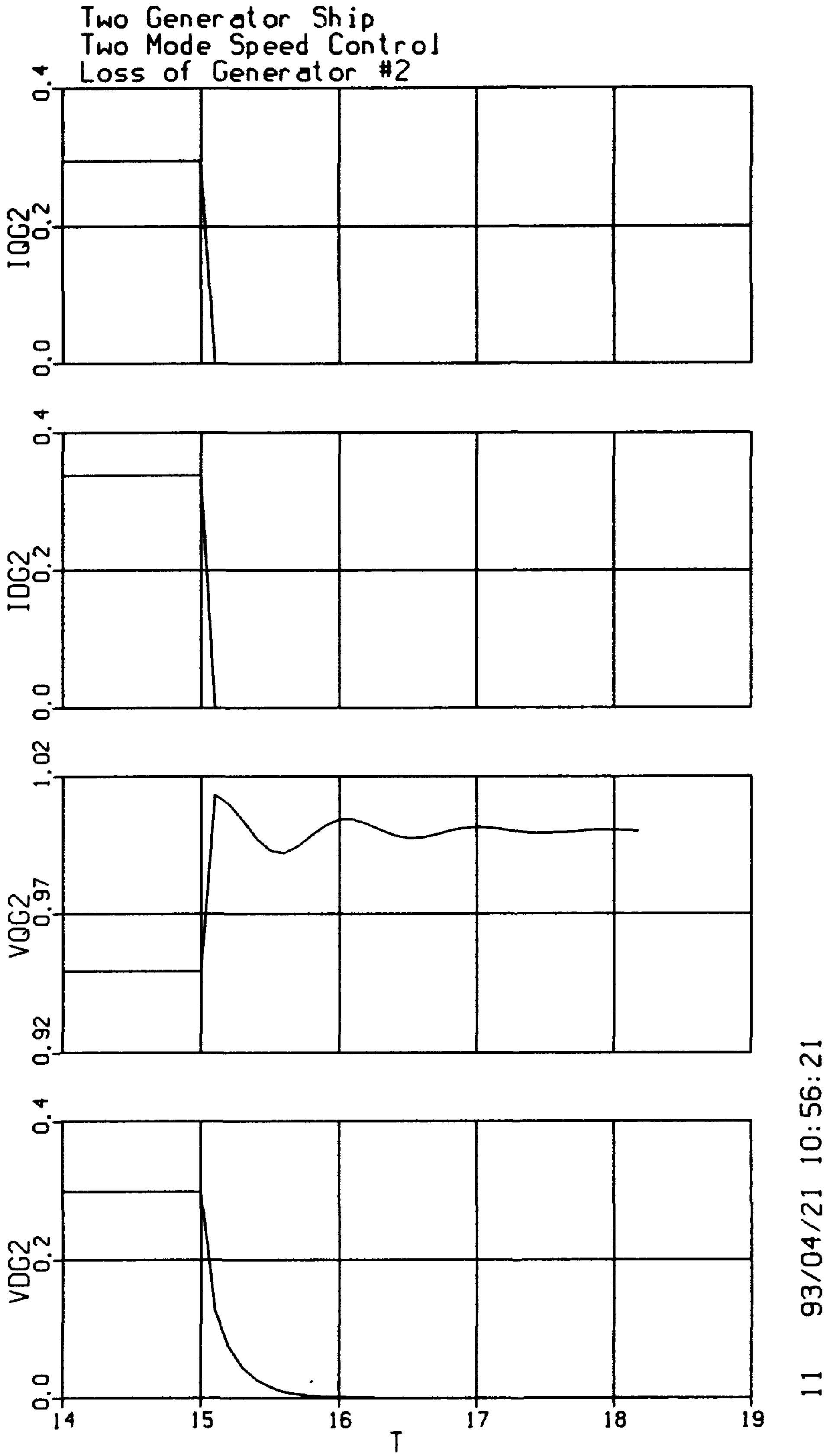

Two Generator Ship
Two Mode Speed Control
Loss of Generator #2
-0.351
IQM1
-0.352
-0.353
0.485
IDM1
0.483
0.481
0.887
VQM1
0.885
0.883
-0.320
VDM1
-0.321
-0.322
14
15
16
17
18
19
T
93/04/21 10:56:21
9

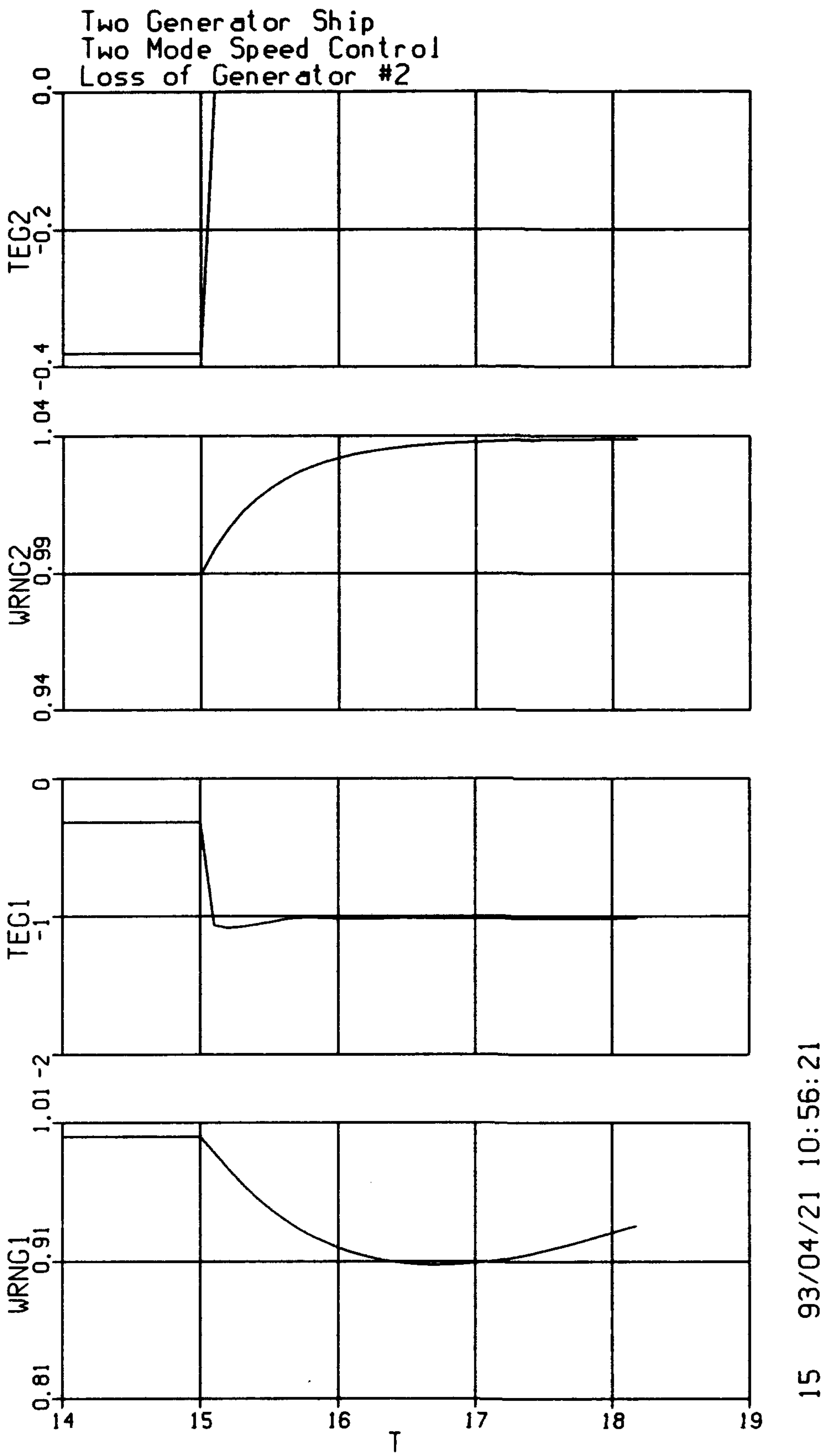


Two Generator Ship
Two Mode Speed Control
Loss of Generator #2
VI1
-0.883
-0.885
-0.887
VR1
0.898
0.896
0.894
BETAR1
1.03
0.98
0.93
IDC1
0.544
0.542
0.540
14
15
16
17
18
19
T
13 93/04/21 10:56:21



Two Generator Ship
Two Mode Speed Control
Loss of Generator #2
IQG1
0.1
0.3
0.5
IDG1
-0.0
0.5
1.0
VQG1
0.50
0.75
1.00
VDG1
-0.0
0.5
1.0
14
15
16
17
18
19
T
10 93/04/21 10:56:21


Two Generator Ship
Two Mode Speed Control
Loss of Generator #2
IQG2
IDG2
VQG2
VDG2
0.4
0.2
0.0
1.02
0.97
0.92
14
15
16
17
18
19
T
93/04/21 10:56:21
11


Two Generator Ship
Two Mode Speed Control
Loss of Generator #2
TEG2
0.0
-0.2
-0.4
WRNG2
1.04
0.99
0.94
TEG1
0
-1
-2
WRNG1
1.01
0.91
0.81
14
15
16
17
18
19
T
15 93/04/21 10:56:21

Appendix E: Notes on Use of ACSL

At the beginning of this research several software packages were considered for possible use. ACSL was selected primarily due to the availability of preexisting code written in that language. The PC-Windows version of ACSL was used throughout this research. This section presents the author's views concerning this software package.

The author has previously used the UNIX version of ACSL and was impressed with its versatility and ease of use. The Windows version is very user friendly, but command line editing is awkward and difficult. When exercising a simulation, the user inputs various commands from the "ACSL prompt." With the UNIX system, the last several commands issued can be recalled by pressing the up arrow key. The command can then be edited as desired and executed by pressing the return key. The windows version does not allow this type of editing. It is possible to open a separate window for command editing, but this requires cutting and pasting with the mouse which can be time consuming. It is not known if this limitation can be overcome by the ACSL authors or if it is a limitation of the windows operating environment. Generating screen plots with ACSL is straightforward, however the Windows version lacks the proper drivers to write the plots into common PC based graphical formats for inclusion in word processor files. It will only write the plots to bitmap or neutral plot files.

The ACSL macro language is very powerful. The concatenation feature of this language is what made it possible to create the simulation models in an object oriented manner. The latest version of ACSL can be purchased with a graphical front end, similar to SIMULAB and SIMULINK which should only enhance the usefulness of the language.

One of the most useful features of the ACSL language is the numerous variety of integration algorithms available for use. The algorithm can also be changed at run-time without recompiling the model. This feature makes it very easy to compare one algorithm against another. The author has found that the variable step algorithms work best with the models developed herein. This is because there are several fast eigenvalues whose transient decays rapidly at the beginning of a simulation. The variable step algorithms take small steps until these transients die out, then are able to take larger steps during the slower ship dynamics transients.

The ACSL package is a translator which writes a FORTRAN program. A separate FORTRAN compiler is required to generate executable code from the ACSL written program. For the DOS and Windows versions of ACSL, the Microsoft FORTRAN Compiler is recommended. This compiler is fraught with problems. The simulations developed herein use several separately written FORTRAN subroutines in the gas turbine and ship dynamics models. These subroutines were up and operating on a UNIX system when provided to the author. According to the documentation, the Microsoft compiler is able to handle all UNIX extensions to FORTRAN-77 and provide many other extensions. This is not the case. Much time was spent getting these programs to compile on the Microsoft compiler when the same file would compile without error on the FORTRAN-77 compiler installed on project ATHENA. There were also occasional problems getting ACSL written code to compile on the Microsoft compiler. This centered around the definition of variables as LOGICAL type and is still not understood by the author. The size of the programs was also a problem for the compiler. After several attempts at

getting one simulation to compile, it was discovered from the Microsoft Helpline consultant that a specific command line switch must be set to compile any program over a certain size. Of course there is no mention of this limitation in the compiler documentation.

Simulation execution time became rather lengthy for the larger simulations. The two generator system would run at about one second of simulation time for every 2-3 minutes of real time. Most of the simulations described in chapter 5 took 3-5 hours to run. The PC used for simulations contained an Intel 80486-DX CPU operating at 33 MHz (one of the faster PC's available at this time). It is recommended that any future research in this area be carried out on a workstation or a mainframe computer.

Appendix F: Dictionary of Variables

In any programming effort such as this there are a large number of variables and constants which must be named. To aid in this task as well as increase the readability of the code, a set of naming conventions was developed. This can be summarized by the following rules:

1. All logical variables begin with the letter "L".
2. Controller gains begin with the letter "G".
3. Controller time constants begin with the letters "TAU".
4. Miscellaneous constants begin with the letter "K".
5. Initial conditions add the suffix "IC" (or "I") to the base variable name.
6. Derivatives add the suffix "D" to the base variable name.
7. When macros are invoked in a program, the concatenation variable is used as a designation of that unit (ie. G1 for generator #1, M1 for motor #1, etc.).

This convention evolved during the course of this research and parts of the code were written by others, so currently it is not in 100% compliance with this convention. However, the above rules are a useful guide to the reader in decyphering the code. What follows is an alphabetical listing of variables with their meaning and units. As mentioned previously, some of the code used was written previously by others, thus the purpose of all internal variables is not known.

AFL1	GT #1 MFC acceleration limit	Unknown
AFRL1	GT #1 MFC feedback signal	Unknown
ALPHA1	GT #1 PLA	Degrees
ALPHA1LL	GT #1 PLA lower limit	Degrees
ALPHA1UL	GT #1 PLA upper limit	Degrees
ALPHAG1	Gen. #1 Ratio of Reactances, See eq. (2.7)	NONE
ALPHAG2	Gen. #2 Ratio of Reactances, See eq. (2.7)	NONE
ALPHAM1	Mtr. #1 Ratio of Reactances, See eq. (2.7)	NONE
ALPHAM2	Mtr. #2 Ratio of Reactances, See eq. (2.7)	NONE
ARLLG1I	GT #1 MFC feedback signal IC	Unknown
BASEKWG1	Gen. #1 Base Power	KW
BASEKWG2	Gen. #2 Base Power	KW
BASEKWM1	Mtr. #1 Base Power	KW
BASEKWM2	Mtr. #2 Base Power	KW
BASENG1	Gen #1 Base Speed	RPM
BASENG2	Gen. #2 Base Speed	RPM
BASENM1	Mtr. #1 Base Speed	RPM
BASENM2	Mtr. #2 Base Speed	RPM
BASEQM1	Mtr. #1 Base Torque	FT.-LBF.
BASEQM2	Mtr. #2 Base Torque	FT.-LBF.
BASEVG1	Gen. #1 Base Voltage	Volts
BASEVG2	Gen. #2 Base Voltage	Volts
BASEVM1	Mtr. #1 Base Voltage	Volts
BASEVM2	Mtr. #2 Base Voltage	Volts
BETAI1	Inverter #1 firing angle	Radians
BETAI2	Inverter #2 firing angle	Radians
BETAM1	Inverter #1 firing angle	Radians
BETAM2	Inverter #2 firing angle	Radians
BETAMINM1	Inverter #1 minimum allowable firing angle	Radians
BETAMINM2	Inverter #2 minimum allowable firing angle	Radians
BETAMAXM1	Inverter #1 maximum allowable firing angle	Radians
BETAMAXM2	Inverter #2 maximum allowable firing angle	Radians
BETAR1	Rectifier #1 firing angle	Radians
BETAR2	Rectifier #2 firing angle	Radians

CQLID1	GT #1 load interface miscellaneous constant	$FT\text{-}LB/RPM^2$
CYL2	Diesel #2 Number of Cylinders	NONE
DELAY2	Diesel #2 Torque time lag	Seconds
DELG1	Gen. #1 Torque (or load) angle	Radians
DELG2	Gen. #2 Torque (or load) angle	Radians
DELI1	Inverter #1 Load angle	Radians
DELI2	Inverter #2 Load angle	Radians
DELM1	Mtr. #1 Load angle	Radians
DELM2	Mtr. #2 Load angle	Radians
DELR1	Rectifier #1 Load angle	Radians
DELR2	Rectifier #2 Load angle	Radians
DELTA2	GT #1 ambient pressure correction factor	None
DELV	Implicit equation solver increment step size	None
DELVTQ1	GT #1 FSEE internal variable	Unknown
DELWF1	GT #1 gas generator internal variable	Unknown
DELWF1I	IC of DELWF1	Unknown
DFL1	GT #1 MFC deceleration limit	Unknown
DFRL1	GT #1 MFC feedback signal	Unknown
DN1	Derivative of GT #1 power turbine speed	RPM/Sec.
DNGG1	GT #1 demand gas generator speed	RPM
DNPT1	Derivative of GT #1 power turbine speed	RPM/Sec.
DNREF1	GT #1 power turbine RPM rate limit	RPM/Sec.
DQ4S1	GT #1 gas generator internal variable	Unknown
DQHR21	GT #1 gas generator internal variable	Unknown
DQPTR1	GT #1 power turbine internal variable	Unknown
DRLLG1I	GT #1 internal variable	Unknown
DRPMDT1	GT #1 FSEE internal variable	Unknown
DT4HS1	GT #1 power turbine internal variable	Unknown
DT51HS1	GT #1 power turbine internal variable	Unknown
DZ1	Hysterisis in motor #1 speed control	per unit
DZ2	Hysterisis in motor #2 speed control	per unit
E01I	GT #1 FSEE internal variable	Unknown
E211	GT #1 FSEE internal variable	Unknown
E221	GT #1 FSEE internal variable	Unknown

E231	GT #1 FSEE internal variable	Unknown
E51	GT #1 FSEE internal variable	Unknown
E61	GT #1 FSEE internal variable	Unknown
E71	GT #1 FSEE internal variable	Unknown
E81	GT #1 FSEE internal variable	Unknown
E91	GT #1 FSEE internal variable	Unknown
EAFERRM1	Mtr. #1 Excitation excitation error signal	per unit
EAFERRM2	Mtr. #2 Excitation excitation error signal	per unit
EAFG1	Gen. #1 Excitation	per unit
EAFG1D	Gen. #1 Excitation derivative	per unit
EAFG1IC	Gen. #1 Excitation initial condition	per unit
EAFG2	Gen. #2 Excitation	per unit
EAFG2D	Gen. #2 Excitation derivative	per unit
EAFG2IC	Gen. #2 Excitation initial condition	per unit
EAFM1	Mtr. #1 Excitation	per unit
EAFM1D	Mtr. #1 Excitation derivative	per unit
EAFM1IC	Mtr. #1 Excitation initial condition	per unit
EAFM2	Mtr. #2 Excitation	per unit
EAFM2D	Mtr. #2 Excitation derivative	per unit
EAFM2IC	Mtr. #2 Excitation initial condition	per unit
EAFM1MAX	Mtr. #1 Maximum excitation	per unit
EAFM1MIN	Mtr. #1 Minimum excitation	per unit
EAFM2MAX	Mtr. #2 Maximum excitation	per unit
EAFM2MIN	Mtr. #2 Minimum excitation	per unit
EAFMAXG1	Gen. #1 Maximum excitation	per unit
EAFMING1	Gen. #1 Minimum excitation	per unit
EAFMAXG2	Gen. #2 Maximum excitation	per unit
EAFMING2	Gen. #2 Minimum excitation	per unit
EAFSM1	Mtr. #1 Excitation set point	per unit
EAFSM2	Mtr #2 Excitation set point	per unit
EDPPG1	Gen #1 D-axis voltage behind subtransient reactance	per unit
EDPPG1D	EDPPG1 derivative	per unit/Sec.
EDPPG1IC	EDPPG1 initial condition	per unit
EDPPG2	Gen #2 D-axis voltage behind subtransient reactance	per unit

EDPPG2D	EDPPG2 derivative	per unit/Sec.
EDPPG2IC	EDPPG2 initial condition	per unit
EDPPM1	Mtr #1 D-axis voltage behind subtransient reactance	per unit
EDPPM1D	EDPPM1 derivative	per unit/Sec.
EDPPM1IC	EDPPM1 initial condition	per unit
EDPPM2	Mtr #2 D-axis voltage behind subtransient reactance	per unit
EDPPM2D	EDPPM2 derivative	per unit/Sec.
EDPPM2IC	EDPPM2 initial condition	per unit
EI1	Inverter #1 AC-side voltage magnitude	per unit
EI2	Inverter #2AC-side voltage magnitude	per unit
EISM1	Mtr #1 desired stator flux magnitude	per unit
EISM2	Mtr #2desired stator flux magnitude	per unit
EMFFB1	GT #1 MFC internal constant	Unknown
EMFSAT1	GT #1 MFC internal variable	Unknown
ENGG1	GT #1 gas generator speed error signal	RPM
ENPT1	GT #1 FSEE internal variable	Unknown
ENPT1I	GT #1 FSEE internal variable	Unknown
EPM1	Round rotor component of EISM1	per unit
EPM2	Round rotor component of EISM2	per unit
EQPG1	Gen #1 Q-axis voltage behind transient reactance	per unit
EQPG1D	EQPG1 derivative	per unit/Sec.
EQPG1IC	EQPG1 initial condition	per unit
EQPG2	Gen #2 Q-axis voltage behind transient reactance	per unit
EQPG2D	EQPG2 derivative	per unit/Sec.
EQPG2IC	EQPG2 initial condition	per unit
EQPM1	Mtr #1 Q-axis voltage behind transient reactance	per unit
EQPM1D	EQPM1 derivative	per unit/Sec.
EQPM1IC	EQPM1 initial condition	per unit
EQPM2	Mtr #2 Q-axis voltage behind transient reactance	per unit
EQPM2D	EQPM2 derivative	per unit/Sec.
EQPM2IC	EQPM2 initial condition	per unit
EQPPG1	Gen #1 Q-axis voltage behind subtransient reactance	per unit
EQPPG1D	EQPPG1 derivative	per unit/Sec.
EQPPG1IC	EQPPG1 initial condition	per unit

EQPPG2	Gen #2 Q-axis voltage behind subtransient reactance	per unit
EQPPG2D	EQPPG2 derivative	per unit/Sec.
EQPPG2IC	EQPPG2 initial condition	per unit
EQPPM1	Mtr #1 Q-axis voltage behind subtransient reactance	per unit
EQPPM1D	EQPPM1 derivative	per unit/Sec.
EQPPM1IC	EQPPM1 initial condition	per unit
EQPPM2	Mtr #2 Q-axis voltage behind subtransient reactance	per unit
EQPPM2D	EQPPM2 derivative	per unit/Sec.
EQPPM2IC	EQPPM2 initial condition	per unit
ER1	Rectifier #1 AC-side voltage magnitude	per unit
ER2	Rectifier #2 AC-side voltage magnitude	per unit
ERRBOUND	Max allowable error for implicit loop solve routine	per unit
ERX1	GT #1 MFC internal variable	Unknown
FARG0	Function look up table index	None
FARG1	Function look up table index	None
FARG2	Function look up table index	None
FARG3	Function look up table index	None
FARGS0	Function look up table index	None
FARGS1	Function look up table index	None
FARGS2	Function look up table index	None
FARGS3	Function look up table index	None
FUEL2	Diesel #2 fuel rack position	per unit
FUEL2MAX	Diesel #2 fuel rack maximum position	per unit
FUEL2MIN	Diesel #2 fuel rack minimum position	per unit
FUELAG2	Diesel #2 injection delay	Seconds
G11	GT #1 power turbine torque limit gain	None
G31	GT #1 power turbine RPM limit gain	None
G51	GT #1 power turbine RPM rate limit gain	None
GBETAR1	Rectifier #1 firing angle controller gain	None
GBETAR2	Rectifier #2 firing angle controller gain	None
GEAFG1	Gen. #1 Excitation controller gain	None
GEAFG2	Gen. #2 Excitation controller gain	None
GEAFM1	Mtr. #1 Excitation controller gain	None
GEAFM2	Mtr. #2 Excitation controller gain	None

GLARGE1	Mtr. #1 speed control "fast mode" gain	None
GLARGE2	Mtr. #2 speed control "fast mode" gain	None
GM1	Mtr. #1 braking resistor conductance value	per unit
GM2	Mtr. #2 braking resistor conductance value	per unit
GSMALL1	Mtr. #1 speed control "slow mode" gain	None
GSMALL2	Mtr. #2 speed control "slow mode" gain	None
GSPEED1	Mtr. #1 speed control gain	None
GSPEED2	Mtr. #2 speed control gain	None
HG1	Gen. #1 inertia constant	Seconds
HG2	Gen. #2 inertia constant	Seconds
HHPS	Propeller / shaft inertia constant	Seconds
HM1	Mtr. #1 inertia constant	Seconds
HM2	Mtr. #2 inertia constant	Seconds
HP1	GT #1 generator horsepower	Horsepower
HP1B	GT #1 power turbine base horsepower	Horsepower
HP1D	GT #1 limited horsepower demand	Horsepower
HP1I	GT #1 generator horsepower IC	Horsepower
HP1ORD	GT #1 ordered horsepower (constant power mode)	Horsepower
HP1ORDI	GT #1 ordered horsepower IC(const. power mode)	Horsepower
HPT1ORD	GT #1 ordered horsepower	Horsepower
IAJXQM1	Product of motor current and xq	per unit
IAJXQM2	Product of motor current and xq	per unit
IAM1	Mtr #1 armature current magnitude	per unit
IAM2	Mtr #2 armature current magnitude	per unit
ICLIM1	GT #1 governor integral control limit	Unknown
ICNTRL1	GT #1 governor integral control	Unknown
ICNTRL1I	GT #1 governor integral control IC	Unknown
ID1GR	Unknown	Unknown
IDBM1	Mtr. #1 braking resistor D-axis current	per unit
IDBM2	Mtr. #2 braking resistor D-axis current	per unit
IDC1	Freq. changer #1 DC-link current	per unit
IDC1D	Freq. changer #1 DC-link current derivative	per unit
IDC1IC	Freq. changer #1 DC-link current IC	per unit
IDC2	Freq. changer #2 DC-link current	per unit

IDC2D	Freq. changer #2 DC-link current derivative	per unit
IDC2IC	Freq. changer #2 DC-link current IC	per unit
IDCBG2	Gen. #2 circuit breaker D-axis current	per unit
IDCOM1	Freq. changer #1 commanded DC-link current	per unit
IDCOM2	Freq. changer #2 commanded DC-link current	per unit
IDCR1	Freq. changer #1 reference DC-link current	per unit
IDCR1D	Freq. chgr. #1 reference DC-link current derivative	per unit/Sec.
IDCR1DMAX	Freq. chgr. #1 ref. DC-link current deriv. max limit	per unit/Sec.
IDCR1DMIN	Freq. chgr. #1 ref. DC-link current deriv. min limit	per unit/Sec.
IDCR1MAX	Freq. chgr. #1 ref. DC-link current max limit	per unit
IDCR1MIN	Freq. chgr. #1 ref. DC-link current min limit	per unit
IDCR1IC	Freq. changer #1 reference DC-link current IC	per unit
IDCR2	Freq. changer #2 reference DC-link current	per unit
IDCR2D	Freq. chgr. #2 reference DC-link current derivative	per unit/Sec.
IDCR2IC	Freq. changer #2 reference DC-link current IC	per unit
IDCR2DMAX	Freq. chgr. #2 ref. DC-link current deriv. max limit	per unit/Sec.
IDCR2DMIN	Freq. chgr. #2 ref. DC-link current deriv. min limit	per unit/Sec.
IDCR2MAX	Freq. chgr. #2 ref. DC-link current max limit	per unit
IDCR2MIN	Freq. chgr. #2 ref. DC-link current min limit	per unit
IDG1	Gen. #1 D-axis stator current	per unit
IDG1IC	Gen. #1 D-axis stator current IC	per unit
IDG1M1	Gen. #1 D-axis stator current on Mtr. #1 base	per unit
IDG2	Gen. #2 D-axis stator current	per unit
IDG2ERR	Gen. #2 D-axis stator current error	per unit
IDG2IC	Gen. #2 D-axis stator current IC	per unit
IDG2M1	Gen. #2 D-axis stator current on Mtr. #1 base	per unit
IDI1	Inverter #1 D-axis current	per unit
IDI2	Inverter #2 D-axis current	per unit
IDL2	Ship's service load D-axis current	per unit
IDM1	Mtr. #1 D-axis stator current	per unit
IDM1IC	Mtr. #1 D-axis stator current IC	per unit
IDM2	Mtr. #2 D-axis stator current	per unit
IDM2IC	Mtr. #2 D-axis stator current IC	per unit
IDR1	Rectifier #1 D-axis current	per unit

IDR2	Rectifier #2 D-axis current	per unit
IDXM1	Mtr. #1 salient component of armatrue reaction flux	per unit
IDXM2	Mtr. #2 salient component of armatrue reaction flux	per unit
IERR1	Freq. chgr. #1 DC-link current error	per unit
IERR1IC	Freq. chgr. #1 DC-link current error IC	per unit
IERR2	Freq. chgr. #2 DC-link current error	per unit
IERR2IC	Freq. chgr. #2 DC-link current error IC	per unit
IGG1	GT. #1 gas generator inertia constant	lbm-ft^2
IITID1	Unknown	Unknown
IQBM1	Mtr. #1 braking resistor Q-axis current	per unit
IQBM2	Mtr. #2 braking resistor Q-axis current	per unit
IQCBG2	Gen. #2 circuit breaker Q-axis current	per unit
IQG1	Gen. #1 Q-axis stator current	per unit
IQG1IC	Gen. #1 Q-axis stator current IC	per unit
IQG2	Gen. #2 Q-axis stator current	per unit
IQG2ERR	Gen. #2 Q-axis stator current error	per unit
IQG2IC	Gen. #2 Q-axis stator current IC	per unit
IQG2M1	Gen. #2 Q-axis stator current on Mtr. #1 base	per unit
IQI1	Inverter #1 Q-axis current	per unit
IQI2	Inverter #2 Q-axis current	per unit
IQL2	Ship's service load Q-axis current	per unit
IQM1	Mtr. #1 Q-axis stator current	per unit
IQM1IC	Mtr. #1 Q-axis stator current IC	per unit
IQM2	Mtr. #2 Q-axis stator current	per unit
IQM2IC	Mtr. #2 Q-axis stator current IC	per unit
IQR1	Rectifier #1 Q-axis current	per unit
IQR2	Rectifier #2 Q-axis current	per unit
JJG	GT #1 generator inertia	lbm-ft^2
JJPROP	Propeller inertia	lbm-ft^2
JJPS	Propeller & shaft inertia	lbm-ft^2
JJPT1	GT #1 power turbine inertia	lbm-ft^2
JJSHFT	Propeller shaft inertia	lbm-ft^2
K00RES	Ship hull dynamics constant	Unknown
K01RES	Ship hull dynamics constant	Unknown

K02RES	Ship hull dynamics constant	Unknown
K03RES	Ship hull dynamics constant	Unknown
K04RES	Ship hull dynamics constant	Unknown
K05RES	Ship hull dynamics constant	Unknown
K06RES	Ship hull dynamics constant	Unknown
K07RES	Ship hull dynamics constant	Unknown
K08RES	Ship hull dynamics constant	Unknown
K09RES	Ship hull dynamics constant	Unknown
K10RES	Ship hull dynamics constant	Unknown
KALARM	GT #1 alarm condition flag	None
KBRAKE1	Mtr. #1 braking resistor constant	None
KBRAKE2	Mtr. #2braking resistor constant	None
KC11	GT #1 governor gain	None
KDFRQ	Seaway encounter wavenumber	Rad. / Ft.
KGC	GT #1 pounds mass to slugs conversion factor	lbm-ft / lbf-sec^2
KGOV2	Diesel #2 governer gain	None
KHOLDPI1	GT #1 governor limit constant	None
KI	GT #1 rotational acceleration conversion factor	lbm-rpm-ft / lbf-sec
KIG1M1	Gen. #1 current base conversion factor	None
KIG2M1	Gen. #2 current base conversion factor	None
KKWG1M1	Gen. #1 power base conversion factor	None
KK1G2M1	Gen. #2 power base conversion factor	None
KPNGG1	GT #1 percent base gas generator speed	1 / RPM
KQHP	GT #1 torque-rpm to horsepower conversion factor	ft-lbf / min-hp
KRAT1	GT #1 FSEE constant	None
KRATE1	GT #1 FSEE constant	None
KSHTDN1	GT #1 shutdown flag	None
KTBL1	GT #1 table overrun flag	None
KTURBO2	Diesel #2 turbocharger constant	None
KVG1M1	Gen. #1 voltage base conversion factor	None
KVG2M1	Gen. #2 voltage base conversion factor	None
KVSHIP	Ship speed per unit conversion factor	Unknown
KZG1M1	Gen. #1 base impedance conversion factor	None

KZG2M1	Gen. #2 base impedance conversion factor	None
LBRAKE1	Mtr. #1 braking condition logical flag	None
LBRAKE2	Mtr. #2 braking condition logical flag	None
LCBG2	Gen. #2 circuit breaker logical flag	None
LDOPLR	Seaway doppler logical flag	None
LFWD1	Mtr. #1 forward torque logical flag	None
LFWD2	Mtr. #2 forward torque logical flag	None
LHEADR	Headreach calculation logical flag (disabled)	None
LHOLD1PI	GT #1 governor logical flag	None
LNGG1A	GT #1 alarm flag	None
LPWRD1	GT #1 power demand flag	None
LSEA	Seaway flag	None
LT541A	GT #1 alarm flag	None
MAXIT	Maximum # of iterations for implicit loop solutions	None
MFKAC1	GT #1 MFC constant	Unknown
MFKFR1	GT #1 MFC constant	Unknown
MFKMV1	GT #1 MFC constant	Unknown
MFKN1	GT #1 MFC constant	Unknown
MFW1	GT #1 MFC constant array	Unknown
N1	Gen. #1 speed	RPM
N1I	Gen. #1 speed IC	RPM
N2	Gen. #2 speed	RPM
NERR1	Gen. #1 speed error	RPM
NGB	Genarator base rpm	RPM
NGG1B	GT #1 base gas generator speed	RPM
NGGL1	GT #1 MFC output gas generator speed	RPM
NMAX2	Diesel #2 maximum speed	RPM
NMIN2	Diesel #2 minimum speed	RPM
NP1PU	#1 Propeller shaft speed	per unit
NP1PUI	#1 Propeller shaft speed IC	per unit
NP1RPM	#1 Propeller shaft speed	RPM
NP1RPMI	#1 Propeller shaft speed IC	RPM
NP2PU	#2 Propeller shaft speed	per unit
NP2PUI	#2 Propeller shaft speed IC	per unit

NP2RPM	#2 Propeller shaft speed	RPM
NP2RPMI	#2 Propeller shaft speed IC	RPM
NPRPMB	Base propeller speed	RPM
NPRPSB	Base propeller speed	RPS
NPT1B	GT #1 power turbine base speed	RPM
NPT1ORD	GT #1 power turbine ordered speed	RPM
NPT1ORDI	GT #1 power turbine ordered speed IC	RPM
NPT1R	GT #1 power turbine reference speed	RPM
NPT1RI	GT #1 power turbine reference speed IC	RPM
NPTL1	GT #1 FSEE internal variable	Unknown
NPTQ1	GT #1 FSEE internal variable	Unknown
NPTQ1I	GT #1 FSEE internal variable IC	Unknown
NPTR1	GT #1 power turbine internal variable	Unknown
NPTR1I	GT #1 power turbine internal variable IC	Unknown
NREF1	GT #1 power turbine speed limit	RPM
NSET2	Diesel #2 governor setpoint speed	RPM
P1	Ship's service real load power setting	per unit
P2	GT #1 compressor inlet pressure	psia
P2T21	GT #1 FSEE internal constant	Unknown
P541	GT #1 power turbine exhaust pressure	psia
P541I	GT #1 power turbine exhaust pressure IC	psia
P54L1	GT #1 FSEE internal constant	Unknown
P54LL1	GT #1 FSEE internal constant	Unknown
P54Q1	GT #1 FSEE internal constant	Unknown
P54Q1I	GT #1 FSEE internal constant IC	Unknown
P54R21	GT #1 internal constant	Unknown
P54R21I	GT #1 internal constant IC	Unknown
PAMB	Ambient pressure	psia
PCNTRL1	GT #1 governor proportional control	None
PCNTRL1I	GT #1 governor proportional control IC	None
PCTID1	Unknown	Unknown
PHIPM1	Mtr. #1 armature current angle	Radians
PHIPM2	Mtr. #2 armature current angle	Radians
PHISM1	Mtr #1 desired power factor angle	Radians

PHISM2	Mtr #2 desired power factor angle	Radians
PNGG1	GT #1 percent gas generator speed	percent
PNGGR1	GT #1 gas generator internal variable	Unknown
PNGGR1I	GT #1 gas generator internal variable IC	Unknown
PS31	GT #1 compressor discharge pressure	psia
PS31I	GT #1 compressor discharge pressure IC	psia
PS3R21	GT #1 gas generator internal variable	Unknown
PS3R21I	GT #1 gas generator internal variable IC	Unknown
PS3WC1	GT #1 MFC internal variable	Unknown
PWRD1	GT #1 governor power demand	percent
PWRD1I	GT #1 governor power demand IC	percent
Q1	Ship's service load reactive power setting	per unit
Q41	GT #1 gas generator internal variable	Unknown
Q4R21	GT #1 gas generator internal variable	Unknown
QCAL1	GT #1 FSEE internal variable	Unknown
QCAL1I	GT #1 FSEE internal variable	Unknown
QGB	Gen. #1 base torque	Ft-lbf
QH1	GT #1 gas generator internal variable	Unknown
QLID1	GT #1 internal variable	Unknown
QLID1I	GT #1 internal variable	Unknown
QMAP1	GT #1 FSEE internal variable	Unknown
QMAP1I	GT #1 FSEE internal variable	Unknown
QMAPL1	GT #1 FSEE internal variable	Unknown
QP1	#1 propeller shaft torque	Ft-lbf
QP1F	#1 propeller shaft friction torque	Ft-lbf
QP1FI	#1 propeller shaft friction torque IC	Ft-lbf
QP1I	#1 propeller shaft torque IC	Ft-lbf
QP1PU	#1 propeller shaft torque	per unit
QP1PUI	#1 propeller shaft torque	per unit
QP2	#2 propeller shaft torque	Ft-lbf
QP2F	#2 propeller shaft friction torque	Ft-lbf
QP2FI	#2 propeller shaft friction torque IC	Ft-lbf
QP2I	#2 propeller shaft torque IC	Ft-lbf
QP2PU	#2 propeller shaft torque	per unit

QP2PUI	#2 propeller shaft torque	per unit
QPBASE	Propeller shaft base torque	per unit
QPSBAF	Propeller shaft breakaway friction	Ft-lbf
QPT1	GT #1 power turbine torque	Ft-lbf
QPT1B	GT #1 power turbine base torque	Ft-lbf
QPT1I	GT #1 power turbine torque IC	Ft-lbf
QPT1PU	GT #1 power turbine torque	per unit
QREF1	GT #1 torque reference	Ft-lbf
RDC1	#1 DC-link resistance	per unit
RDC2	#2 DC-link resistance	per unit
RS1PU0	Ship resistance component	Unknown
RS1PU1	Ship resistance component	Unknown
RS1PU2	Ship resistance component	Unknown
RS1PU3	Ship resistance component	Unknown
RS1PU	Ship resistance component	Unknown
RS1PUI0	Ship resistance component	Unknown
RS1PUI1	Ship resistance component	Unknown
RS1PUI2	Ship resistance component	Unknown
RS1PUI3	Ship resistance component	Unknown
RS1PUI	Ship resistance component	Unknown
SEAFREQ	Doppler shifted wave frequency	Rad. / Sec.
SEATIME	Phase shifted time for seaway calculation	Seconds
SNEGVL1	GT #1 FSEE internal variable	Unknown
SPDERR1IC	#1 shaft speed error IC	per unit
SPDERR2	Diesel #2 speed error	RPM
SPDERR2IC	#2 shaft speed error IC	per unit
SPDREF1	Propeller #1 shaft speed reference	per unit
SPDREF2	Propeller #2 shaft speed reference	per unit
SPEEDERR1	Propeller #1 shaft speed error	per unit
SPEEDERR2	Propeller #2 shaft speed error	per unit
SQRTH2	GT #1 nondimensional temperature constant	None
SWITCHVAR1	Propeller #1 shaft speed error with hysterisis	per unit
SWITCHVAR2	Propeller #2 shaft speed error with hysterisis	per unit
T0SEA	Time reference for seaway calculations	Seconds

T2	GT #1 compressor inlet temperature	° R
T41	GT #1 gas generator internal variable	Unknown
T4P1	GT #1 gas generator internal variable	Unknown
T4PL1	GT #1 gas generator internal variable	Unknown
T4R21	GT #1 gas generator internal variable	Unknown
T4U1	GT #1 gas generator internal variable	Unknown
T511	GT #1 gas tenerator exhaust temperature	° F
T51P1	GT #1 power turbine internal variable	Unknown
T51PL1	GT #1 power turbine internal variable	Unknown
T51Q1	GT #1 power turbine internal variable	Unknown
T51R21	GT #1 power turbine internal variable	Unknown
T51U1	GT #1 power turbine internal variable	Unknown
T541	GT #1 power turbine inlet temperature	° F
TABTR11	GT #1 FSEE internal variable	Unknown
TALPHA1	GT #1 governor load compensation value	None
TAMB	GT #1 ambient temperature	° F
TAUBETAR1	Rectifier #1 controller time constant	Seconds
TAUBETAR2	Rectifier #2 controller time constant	Seconds
TAUEAFG1	Gen. #1 field excitation controller time constant	Seconds
TAUEAFG2	Gen. #2 field excitation controller time constant	Seconds
TAUEAFM1	Mtr. #1 field excitation controller time constant	Seconds
TAUEAFM2	Mtr. #2 field excitation controller time constant	Seconds
TAUFAST1	Staft #1 speed controller "fast mode" time constant	Seconds
TAUFAST2	Staft #2 speed controller "fast mode" time constant	Seconds
TAUGOV2	Diesel #2 governer time constant	Seconds
TAUSLOW1	Staft #1 speed controller "slow mode" time constant	Seconds
TAUSLOW2	Staft #2 speed controller "slow mode" time constant	Seconds
TAUSPEED1	Staft #1 speed controller time constant	Seconds
TAUSPEED2	Staft #2 speed controller time constant	Seconds
TC11	GT #1 governor time constant	Seconds
TDOPG1	Gen. #1 D-axis open circuit transient time constant	Seconds
TDOPG2	Gen. #2 D-axis open circuit transient time constant	Seconds
TDOPM1	Mtr. #1 D-axis open circuit transient time constant	Seconds
TDOPM2	Mtr. #2 D-axis open circuit transient time constant	Seconds

TDOPPG1	Gen. #1 D-axis open ckt subtransient time constant	Seconds
TDOPPG2	Gen. #2 D-axis open ckt subtransient time constant	Seconds
TDOPPM1	Mtr. #1 D-axis open ckt subtransient time constant	Seconds
TDOPPM2	Mtr. #2 D-axis open ckt subtransient time constant	Seconds
TDT541	GT #1 gas gen. exhaust to PT inlet temp difference	° F
TEG1	Gen. #1 electromagnetic torque	per unit
TEG1IC	Gen. #1 electromagnetic torque IC	per unit
TEG2	Gen. #2 electromagnetic torque	per unit
TEG2IC	Gen. #2 electromagnetic torque IC	per unit
TEM1	Mtr. #1 electromagnetic torque	per unit
TEM2	Mtr. #2 electromagnetic torque	per unit
TESM1	Gen. #1 electromagnetic torque for GT use	ft-lbf
TESM1I	Gen. #1 electromagnetic torque for GT use IC	ft-lbf
TGLAG1	GT #1 FSEE internal variable	Unknown
THDOT21	GT #1 internal variable	Unknown
THET2N	GT #1 nondimensional constant	None
THETA2	GT #1 nondimensional temperature	None
THRESHOLD1	Shaft #1 speed error required for switching control modes	per unit
THRESHOLD2	Shaft #2 speed error required for switching control modes	per unit
THTA2V	GT #1 constant	None
TIC1	GT #1 throttle input command	Degrees
TIC1LL	GT #1 throttle input command lower limit	Degrees
TIC1UL	GT #1 throttle input command upper limit	Degrees
TICMD1	GT #1 governor control signal	Degrees
TICMD1I	GT #1 governor control signal IC	Degrees
TICN1	GT #1 governor PI control signal	Degrees
TICN1I	GT #1 governor PI control signal IC	Degrees
TICRL1LL	GT #1 governor control signal lower rate limit	Deg. / Sec.
TICRL1UL	GT #1 governor control signal upper rate limit	Deg. / Sec.
TICS1	GT #1 governor power demand control signal	Degrees
TICS1I	GT #1 governor power demand control signal IC	Degrees
TMAP	Diesel #1 torque map table	per unit
TMG2	Gen. #2 mechanical torque	per unit

TMM1	Mtr. #1 mechanical torque	per unit
TMM2	Mtr. #2 mechanical torque	per unit
TORQ2	Diesel #2 instantaneous torque	per unit
TP1PU	Shaft #1 propeller thrust	per unit
TP1PUI	Shaft #1 propeller thrust IC	per unit
TP2PU	Shaft #2 propeller thrust	per unit
TP2PUI	Shaft #2 propeller thrust IC	per unit
TQOPPG1	Gen. #1 Q-axis open ckt subtransient time constant	Seconds
TQOPPG2	Gen. #2 Q-axis open ckt subtransient time constant	Seconds
TQOPPM1	Mtr. #1 Q-axis open ckt subtransient time constant	Seconds
TQOPPM2	Mtr. #2 Q-axis open ckt subtransient time constant	Seconds
TSEA	Seaway wave period	Seconds
TSTOP	Simulation termination time	Seconds
TURBOLAG2	Diesel #2 turbocharger lag	Seconds
TUT4H1	GT #1 gas generator internal variable	Unknown
TUT51H1	GT #1 power turbine internal variable	Unknown
TVSOREF	Reference ship stopping time	Seconds
U1	Rectifier #1 control variable	None
U1D	Rectifier #1 control variable IC	None
U2	Rectifier #2 control variable	None
U2D	Rectifier #2 control variable IC	None
UMAX1	Rectifier #1 control variable maximum value	None
UMAX2	Rectifier #2 control variable maximum value	None
UMIN1	Rectifier #1 control variable minimum value	None
UMIN2	Rectifier #2 control variable minimum value	None
VDBIC	Bus D-axis voltage IC	per unit
VDBUS	Bus D-axis voltage	per unit
VDCBG2	Gen. #2 circuit breaker voltage	per unit
VDERR	D-axis voltage error for implicit loop calculation	per unit
VDG1	Gen. #1 D-axis terminal voltage	per unit
VDG2	Gen. #2 D-axis terminal voltage	per unit
VDI1	Inverter #1 D-axis terminal voltage	per unit
VDI2	Inverter #2 D-axis terminal voltage	per unit
VDM1	Mtr. #1 D-axis terminal voltage	per unit

VDM2	Mtr. #2 D-axis terminal voltage	per unit
VDR1	Rectifier #1 D-axis terminal voltage	per unit
VDIR	Rectifier #2 D-axis terminal voltage	per unit
VERRG1	Gen. #1 terminal voltage error	per unit
VERRG2	Gen. #2 terminal voltage error	per unit
VI1	Inverter #1 DC-side voltage	per unit
VI2	Inverter #2 DC-side voltage	per unit
VN1	GT #1 FSEE power turbine speed reference voltage	volts
VNSF1	GT #1 FSEE power turbine speed scale factor	RPM / volt
VQ1	GT #1 FSEE power turbine torque reference voltage	volts
VQBIC	Bus Q-axis voltage IC	per unit
VQBUS	Bus Q-axis voltage	per unit
VQCBG2	Gen. #2 circuit breaker voltage	per unit
VQERR	Q-axis voltage error for implicit loop calculation	per unit
VQG1	Gen. #1 Q-axis terminal voltage	per unit
VQG2	Gen. #2 Q-axis terminal voltage	per unit
VQI1	Inverter #1 Q-axis terminal voltage	per unit
VQI2	Inverter #2 Q-axis terminal voltage	per unit
VQM1	Mtr. #1 Q-axis terminal voltage	per unit
VQM2	Mtr. #2 Q-axis terminal voltage	per unit
VQR1	Rectifier #1 Q-axis terminal voltage	per unit
VQR2	Rectifier #2 Q-axis terminal voltage	per unit
VQSF1	GT #1 FSEE power turbine torque scale factor	lbf-ft / volt
VR1	Rectifier #1 DC-side voltage	per unit
VR2	Rectifier #1 DC-side voltage	per unit
VRATE1	GT #1 FSEE rate limit	volts
VRSF1	GT #1 FSEE rate limit scale factor	rpm / sec-volt
VS1PU0	Zero ship speed	per unit
VS1PU10	(Ship speed)^{10}	per unit
VS1PU10I	(Ship speed)^{10} IC	per unit
VS1PU2	(Ship speed)^{2}	per unit
VS1PU2I	(Ship speed)^{2} IC	per unit
VS1PU3	(Ship speed)^{3}	per unit
VS1PU3I	(Ship speed)^{3} IC	per unit

VS1PU4	(Ship speed)^4	per unit
VS1PU4I	(Ship speed)^4 IC	per unit
VS1PU5	(Ship speed)^5	per unit
VS1PU5I	(Ship speed)^5 IC	per unit
VS1PU6	(Ship speed)^6	per unit
VS1PU6I	(Ship speed)^6 IC	per unit
VS1PU7	(Ship speed)^7	per unit
VS1PU7I	(Ship speed)^7 IC	per unit
VS1PU8	(Ship speed)^8	per unit
VS1PU8I	(Ship speed)^8 IC	per unit
VS1PU9	(Ship speed)^9	per unit
VS1PU9I	(Ship speed)^9 IC	per unit
VS1PU	Ship speed	per unit
VT12	Unknown	Unknown
VTG1	Gen. #1 terminal voltage	per unit
VTG2	Gen. #2 terminal voltage	per unit
VTM1	Mtr. #1 terminal voltage	per unit
VTM2	Mtr. #2 terminal voltage	per unit
VTOP1	GT #1 topping governor value	Unknown
VTREFG1	Gen. #1 terminal voltage reference value	per unit
VTREFG2	Gen. #2 terminal voltage reference value	per unit
VTRQGS1	GT #1 FSEE torque limiting value	Unknown
W41	GT #1 gas generator internal variable	Unknown
W4R21	GT #1 gas generator internal variable	Unknown
W541	GT #1 power turbine internal variable	Unknown
W54R21	GT #1 power turbine internal variable	Unknown
WAVE	Seaway wave wavelength	per unit
WEFSEA	Radian frequency of waves	Rad. / Sec.
WESEA	Seaway velocity factor	per unit
WESEAMG	Seaway internal varialbe	Unknown
WESMAX	Maximum sea induced variation in ship speed	per unit
WFAC1	GT #1 MFC internal variable	Unknown
WFSR21	GT #1 gas generator internal varaible	Unknown
WFUEL1	GT #1 MFC fuel flow rate	Unknown

WFUEL1I	GT #1 MFC fuel flow rate IC	Unknown
WMG1	Gen. #1 rotational speed	Rad. / Sec.
WMG2	Gen. #2 rotational speed	Rad. / Sec.
WMG2D	Gen. #2 rotational acceleration	Rad. / $Sec.^2$
WMM1	Mtr. #1 rotational speed (electrical)	Rad. / Sec.
WMM1D	Mtr. #1 rotational acceleration	Rad. / $Sec.^2$
WMM1IC	Mtr. #1 rotational speed IC	Rad. / Sec.
WMM2	Mtr. #2 rotational speed (electrical)	Rad. / Sec.
WMM2D	Mtr. #2 rotational acceleration	Rad. / $Sec.^2$
WMM2IC	Mtr. #2 rotational speed IC	Rad. / Sec.
WO	Base electrical frequency	Rad. / Sec.
WRN1ORD	GT #1 ordered speed	per unit
WRN1ORDIC	GT #1 ordered speed IC	per unit
WRNG1	Gen. #1 rotational speed	per unit
WRNG1IC	Gen. #1 rotational speed IC	per unit
WRNG2	Gen. #2 rotational speed	per unit
WRNG2IC	Gen. #2 rotational speed IC	per unit
WRNM1	Mtr. #1 rotational speed	per unit
WRNM2	Mtr. #2 rotational speed	per unit
XDC1	DC-link #1 reactance	per unit
XDC2	DC-link #2 reactance	per unit
XDG1	Gen. #1 D-axis synchronous reactance	per unit
XDG2	Gen. #2 D-axis synchronous reactance	per unit
XDM1	Mtr. #1 D-axis synchronous reactance	per unit
XDM2	Mtr. #2 D-axis synchronous reactance	per unit
XDMXQM1	Mtr. #1 difference between Xd and Xq	per unit
XDMXQM2	Mtr. #2 difference between Xd and Xq	per unit
XDPG1	Gen. #1 D-axis transient reactance	per unit
XDPG2	Gen. #2 D-axis transient reactance	per unit
XDPM1	Mtr. #1 D-axis transient reactance	per unit
XDPM2	Mtr. #2 D-axis transient reactance	per unit
XDPPG1	Gen. #1 D-axis subtransient reactance	per unit
XDPPG2	Gen. #2 D-axis subtransient reactance	per unit
XDPPM1	Mtr. #1 D-axis subtransient reactance	per unit

XDPPM2	Mtr. #2 D-axis subtransient reactance	per unit
XG1	Gen. #1 Transmission line reactance	per unit
XG2	Gen. #2 Transmission line reactance	per unit
XK3L1	GT #1 FSEE internal variable	Unknown
XL1	Rectifier #1 transmission line reactance	per unit
XLG1	Gen. #1 leakage reactance	per unit
XLG2	Gen. #2 leakage reactance	per unit
XLM1	Mtr. #1 leakage reactance	per unit
XLM2	Mtr. #2 leakage reactance	per unit
XM1	Mtr. #1 transmission line reactance	per unit
XMV1	GT #1 MFC internal variable	Unknown
XQG1	Gen. #1 Q-axis synchronous reactance	per unit
XQG2	Gen. #2 Q-axis synchronous reactance	per unit
XQM1	Mtr. #1 Q-axis synchronous reactance	per unit
XQM2	Mtr. #2 Q-axis synchronous reactance	per unit
XQPPG1	Gen. #1 D-axis subtransient reactance	per unit
XQPPG2	Gen. #2 D-axis subtransient reactance	per unit
XQPPM1	Mtr. #1 D-axis subtransient reactance	per unit
XQPPM2	Mtr. #2 D-axis subtransient reactance	per unit
XVS0REF	Reference ship stopping distance	Unknown